U.S. STRONG-MOTION EARTHQUAKE INSTRUMENTATION

Proceedings
of the
U.S. NATIONAL WORKSHOP ON STRONG-MOTION EARTHQUAKE INSTRUMENTATION

April 12-14, 1981
Santa Barbara, California

Sponsored by
National Science Foundation

Edited by W.D. Iwan

DEDICATION

This volume is dedicated to the memory of Dr. R. B. (Fritz) Matthiesen (1926-1981). For more than eight years with the U.S. Geological Survey, Dr. Matthiesen played a leading role in the U.S. strong-motion program. The present nationwide network of strong-motion instruments is largely a result of his foresight and persistent efforts. The country is indebted to him and his colleagues will greatly miss him.

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CONVENING ORGANIZATIONS

Earthquake Engineering Research Institute
Universities Council for Earthquake Engineering Research

SPONSORING ORGANIZATION

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PREFACE

The U.S. National Workshop on Strong-Motion Earthquake Instrumentation was held April 12-14, 1981 on the campus of Westmont College in Santa Barbara, California. The Workshop was organized by a Steering Committee appointed by the Earthquake Engineering Research Institute and the Universities Council for Earthquake Engineering Research. This volume is the product of the combined efforts of those in attendance.

The objectives of the Workshop were: 1) to review existing strong-motion instrumentation programs in the U.S., 2) to develop a unified strategy for the deployment of strong-motion instruments both in the free-field and in buildings, and 3) to formulate a plan for the coordination of existing strong-motion programs, the on-going installation and operation of instruments and the management of strong-motion data. To achieve these objectives, the Workshop was organized into a number of Working Committees covering the major areas to be addressed. The reports of the individual Working Committees are incorporated as chapters in this volume.

Experts in earthquake engineering and seismology were invited from all over the nation to participate in the Workshop. In addition, experts were invited from a number of foreign countries. Prior to the Workshop a Strong-Motion Instrumentation Survey was sent to all U.S. organizations known to have active strong-motion programs. The results of this Survey were made available to the Workshop delegates and are included in this volume.

I would like to express my sincere appreciation to all of the participants for their many contributions to the Workshop. I would especially like to thank the Working Committee Chairman and Vice-Chairmen; J.T.P. Yao, L. Lund, G. C. Hart, T-L. Teng, D. K. Ostrom, C. B. Crouse, D. E. Hudson, and M. A. Sozen. These individuals put in many hours both during and after the Workshop in order to insure its success. A word of thanks is also due Westmont College for the excellent support they provided. I wish to express my deepest personal thanks to Sharon Vedrode Beckenbach who so gracefully handled all of the administrative details of the Workshop and the preparation of this volume. Finally, on behalf of all the participants I gratefully acknowledge the National Science Foundation whose financial support made the Workshop possible.

Wilfred D. Iwan
Chairman, Steering Committee

TABLE OF CONTENTS

	PAGE
WORKSHOP PARTICIPANTS	iii
PREFACE	v
RESOLUTION	viii
CHAPTER 1 - SUMMARY	1
1.1 INTRODUCTION	1
1.2 EXISTING PROGRAMS	3
1.3 FUTURE NEEDS	6
1.4 PROCESSING, CATALOGING, ARCHIVING AND DISSEMINATION OF STRONG-MOTION DATA	8
1.5 PROGRAM MANAGEMENT AND FUNDING	9
1.6 CONCLUSIONS	11
CHAPTER 2 - EXISTING STRONG-MOTION PROGRAMS	13
2.1 INTRODUCTION	13
2.2 SUMMARY OF STRONG-MOTION PROGRAMS	14
2.3 SUPPLEMENTAL COMMENTARY	14
2.4 CURRENT DATA PROCESSING FACILITIES	16
CHAPTER 3 - FUTURE NEEDS	29
3.1 INTRODUCTION	29
3.2 NEEDS FOR THE CHARACTERIZATION OF STRUCTURAL RESPONSE	29
3.3 NEEDS FOR THE CHARACTERIZATION OF STRONG MOTION INPUT AND SOIL/STRUCTURE SYSTEM	33
3.3.1 FIXED SURFACE ARRAYS	33
3.3.2 DENSE THREE-DIMENSIONAL ARRAYS	36
3.3.3 MOBILE ARRAYS	37
3.4 STRONG MOTION INSTRUMENT NEEDS	38
3.5 RECOMMENDED COOPERATIVE PROGRAM	39

PAGE

CHAPTER 4 - PROCESSING, CATALOGING, ARCHIVING AND DISSEMINATION OF STRONG-MOTION DATA 41

4.1 INTRODUCTION 41
4.2 PROBLEMS ASSOCIATED WITH STANDARD METHODS OF DATA PROCESSING 42
4.3 UNRESOLVED QUESTIONS CONCERNING DIGITAL INSTRUMENTS . . 43
4.4 INSTRUMENT EVALUATION AND CALIBRATION 44
4.5 ARCHIVING, CATALOGING AND DISSEMINATION OF STRONG-MOTION DATA 45
4.6 CONCLUSIONS 49

CHAPTER 5 - PROGRAM MANAGEMENT AND FUNDING 51

5.1 INTRODUCTION 51
5.2 PROGRAM MANAGEMENT 51

5.2.1 NATIONAL COMMITTEE ON STRONG EARTHQUAKE MOTION 52
5.2.2 EXISTING NSF/USGS STRONG-MOTION PROGRAM 53

5.3 FUNDING 54
5.4 STATE AND LOCAL STRONG-MOTION PROGRAMS 56

REFERENCES 57

APPENDIX A - STRONG-MOTION EARTHQUAKE INSTRUMENTATION SURVEY A1

APPENDIX B - LIST OF RESPONDENT ORGANIZATIONS AND CONTACT PERSONS B1

RESOLUTION

The U.S. National Workshop on Strong-Motion Earthquake Instrumentation unanimously adopted the following resolution during a general session on April 14, 1981.

Earthquakes are an ever present threat to life and property in many parts of the United States. The expected life loss and property damage from future earthquakes is currently unacceptable. However, the impact of the earthquake hazard could be substantially reduced if it were possible to better anticipate the effects of strong ground shaking on structures and other facilities and thereby take steps to economically design these structures and facilities to achieve desired safety levels. The collection, processing and archiving of strong-motion accelerograph data are fundamental and essential to the accomplishment of this goal. Current programs must be expanded to obtain the needed data in sufficient quality and quantity to achieve a substantial hazard reduction within the next decade. This will require the continued cooperation between interested members of both the engineering and scientific communities.

The Workshop delegates believe that it is important that additional strong-motion data be obtained to improve the capability to predict strong ground motion at a site and to evaluate the effect of strong ground motion on existing and future structures. The Workshop delegates therefore recommend the following:

1. The development and employment of highly reliable digital accelerographs is encouraged.

2. Although present methods of data collection and analysis provide reasonable results, there is continuing need for the development of improved signal processing techniques applicable to strong-motion data.

3. Standards of documentation should be developed for existing and future strong-motion data including site characteristics. This information should be stored and cataloged in one or two national depositories and made readily accessible to users.

4. Expedient procedures should be developed so that those concerned about structural safety can obtain copies of important accelerograms within a few days of record recovery following a strong earthquake.

5. The Universities Council for Earthquake Engineering Research and the Earthquake Engineering Research Institute should jointly create, preferably through the National Academy of Engineering, the National Academy of Science and the National Research Council, a committee for coordination of the U.S. Strong-Motion Instrumentation Program.

6. A vigorous effort should be made to increase both the level and diversity of funding for strong-motion instrumentation programs.

7. States and local municipalities in zones of high seismic risk should examine the program of the State of California in the organization and funding of strong-motion instrumentation systems to determine the extent to which this program might be adapted or modified to meet conditions elsewhere.

CHAPTER 1

SUMMARY

1.1 INTRODUCTION

The problem of safeguarding life and property from the destructive effects of earthquakes is truly national in scope. Although many regions of the United States have relatively low seismicity, damaging earthquakes have historically occurred from coast to coast. In fact, some of the most severe seismic disturbances experienced during the short history of this country occurred in the mid-west and east; the New Madrid earthquakes of 1811 and 1812 and the Charleston earthquake of 1886. Figure 1.1 shows the geographic distribution of earthquakes within the United States based on intensity (observed local effects).

As the nation's population and the output of goods and services have become more and more concentrated geographically, the potential for loss associated with a single earthquake event has become correspondingly greater. It has been estimated that a major earthquake in some regions of the country could result in the loss of tens of thousands of lives and cost on the order of one hundred billion dollars in property damage and lost output and productivity. Such an occurrence would have to be considered a disaster of national proportions no matter where in the country it might occur.

The ultimate goal of earthquake hazard mitigation research is to gain sufficient understanding of the phenomena involved in an earthquake to be able to devise socially and economically acceptable means of minimizing the loss of life and property resulting from such an event. In order to design safe, economical structures and facilities in earthquake-prone regions of the United States, it is necessary to understand both the nature of the ground motion that these systems may be expected to experience during their lifetime and the nature of their response to this excitation. This understanding can ultimately come only from the measurement of the near-field strong ground motion and system response resulting from actual damaging earthquakes.

The first recordings of strong ground motion were obtained during the damaging Long Beach earthquake of 1933 from special instruments designed and installed only a year earlier. Since this event, the design of strong-motion instruments has been greatly improved and these instruments have been deployed throughout the United States and in many seismic regions the world. Thanks to the unwavering commitment of those

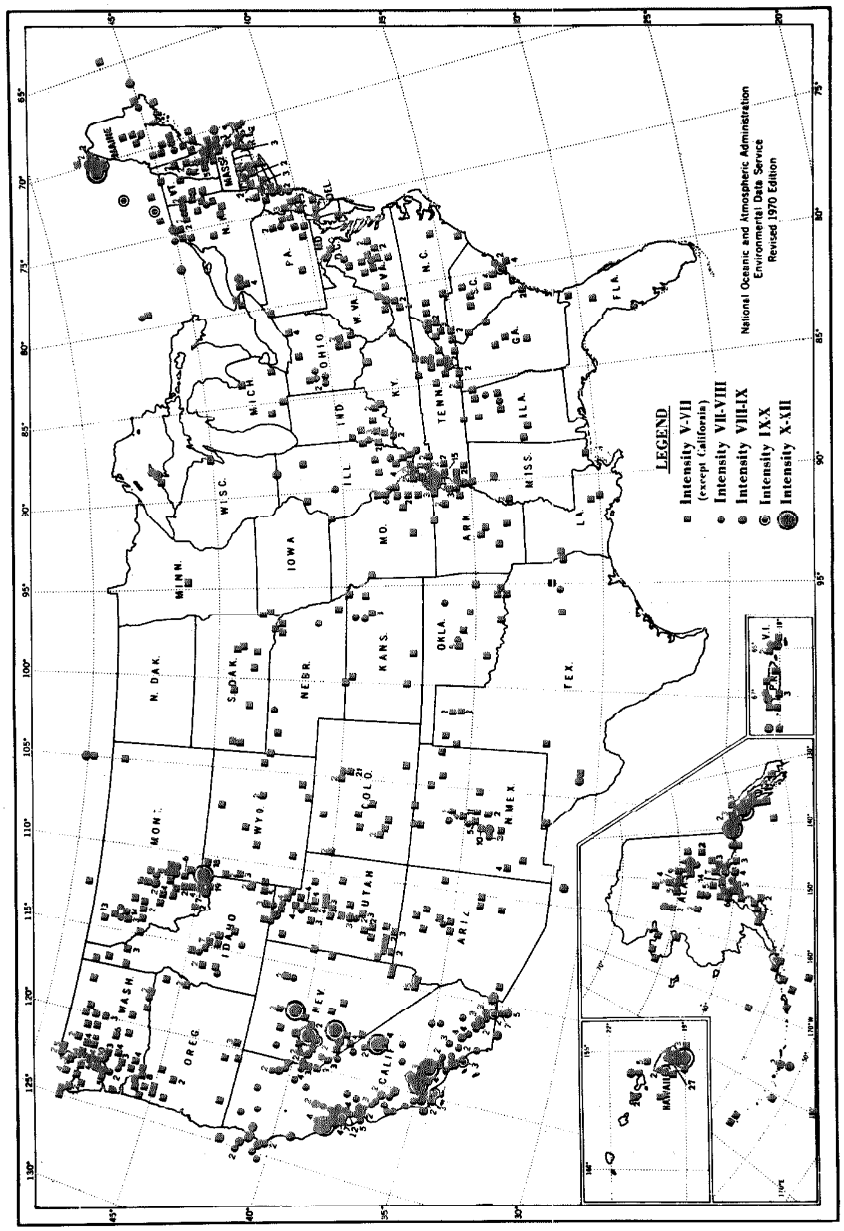


FIGURE 1.1. EARTHQUAKES (INTENSITY V AND ABOVE) IN THE U.S. THROUGH 1970.

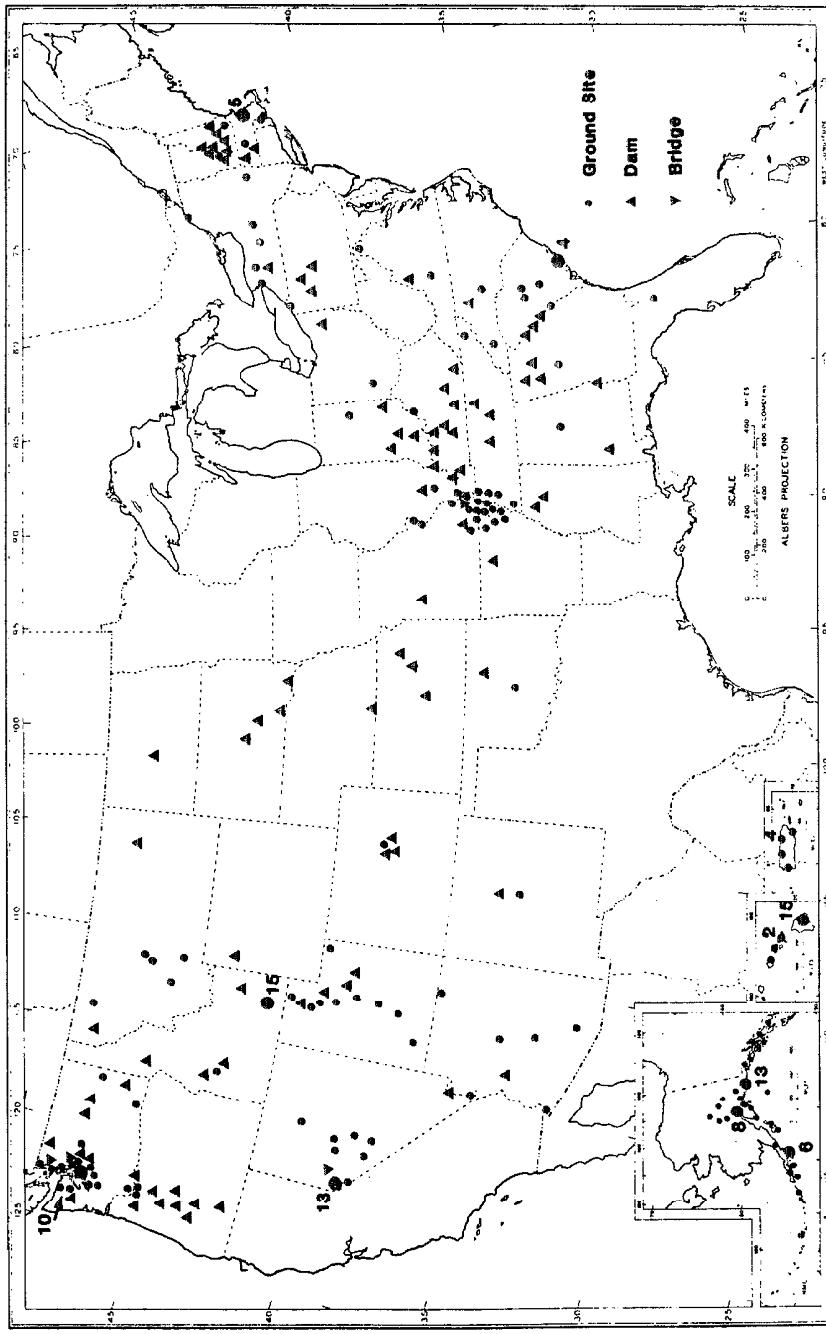
involved in the initial stages of strong-motion instrumentation deployment, data from a number of significant earthquake events have been recorded. The data obtained from these events have had a profound impact on current design codes and criteria. However, there is still a pressing need for further improvement of these codes and criteria which can only be accomplished by the acquisition of additional data. Such data would not only help to reduce the loss of life and property, but would lead to greater cost effectiveness in the design of all systems. It would also help to reduce the substantial economic and technological losses that often result from delays in construction of critical facilities due to presently inadequate or inconclusive ground motion and response data.

Prior to the National Workshop on Strong-Motion Instrumentation a questionnaire was sent to individuals active in earthquake hazard mitigation. The overwhelming response of these individuals was that even though the accomplishments of the U.S. strong-motion program to date were impressive, there was much that remained to be done in this important field. They pointed in particular to: 1) the need for an increased number of integrated dense arrays of common time base instruments at ground level, below ground level and in structures, 2) the need for further development of reliable digital accelerographs and other new technology instruments, 3) the need for expanded instrumentation of special structures and facilities, and 4) the need for more strong-motion data outside of California. A majority of those responding felt that present data processing techniques and archiving were acceptable, but most felt that significant improvements could still be made in these areas. A substantial majority of those queried felt that there was a need for the creation of some form of a national committee to advise and coordinate the various strong-motion programs throughout the country.

The Workshop was organized around four working committees covering the major subject areas: 1) existing programs, 2) future needs, 3) data processing, archiving and dissemination, and 4) program management and funding. A summary of the findings and recommendations of these working committees is given below.

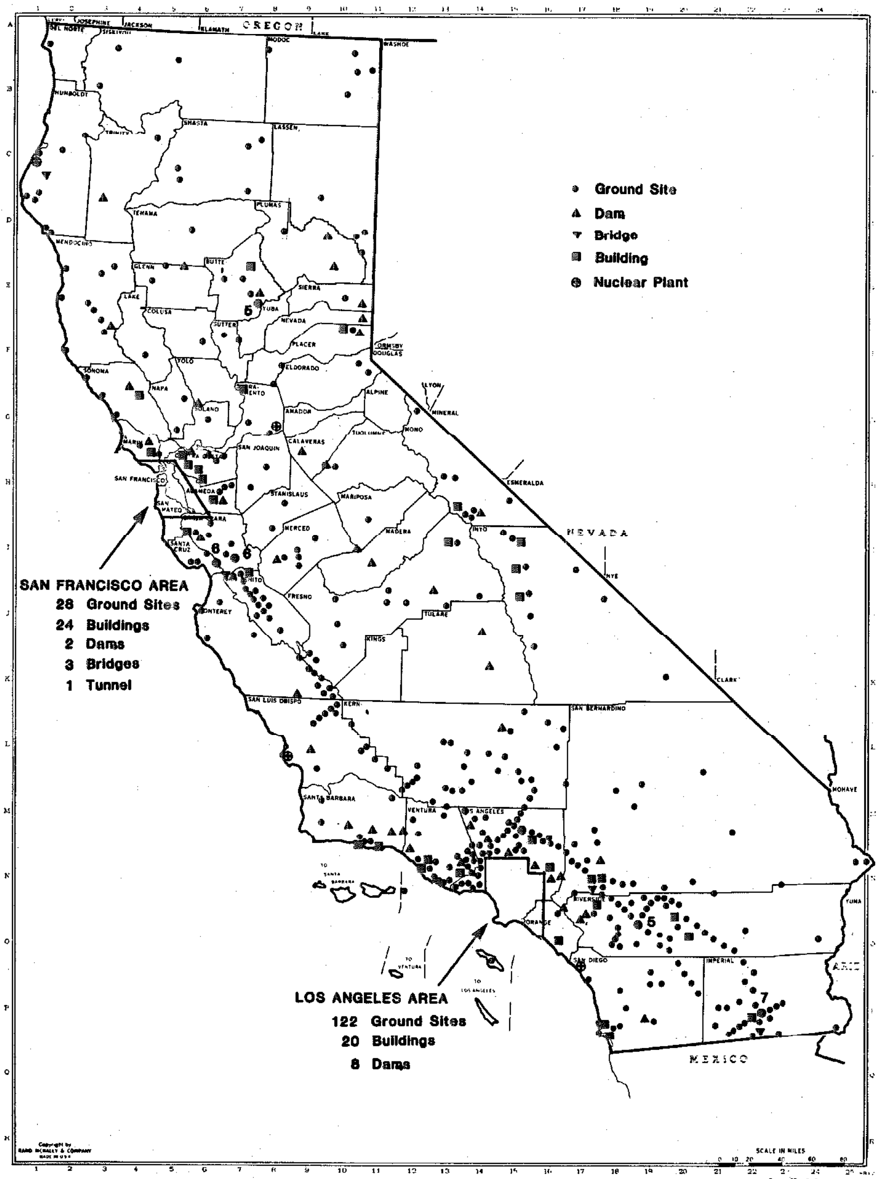
1.2 EXISTING PROGRAMS

According to estimates of equipment manufacturers, nearly 3,000 modern film-recording and digital strong-motion accelerographs have been manufactured and deployed in the United States. These instruments have been installed in a variety of geographical locations; some in the free field and some in buildings or other structures. A few of the instruments have been taken out of service over the years, but most are presently in service in an operationally ready state. Figures 1.2 and 1.3 show the known locations of accelerographs in the United States outside of California and in California, respectively, as of April 30, 1981. These figures, supplied by the U.S. Geological Survey, exclude



April 30, 1981

FIGURE I.2. KNOWN ACCELEROGRAPHS IN THE U.S. OUTSIDE OF CALIFORNIA EXCLUDING COMMERCIAL NUCLEAR POWERED ELECTRICAL GENERATING PLANTS.



April 30, 1981

FIGURE 1.3. KNOWN ACCELEROGRAPHS IN CALIFORNIA, EXCLUDING INSTRUMENTS REQUIRED BY BUILDING CODES

instruments required by building codes and those in commercial nuclear-powered electrical generating plants.

The strong-motion instruments indicated in the figures have been deployed by a number of different organizations and for a variety of different purposes. The organizations owning the largest numbers of instruments are: The City of Los Angeles with 486 instruments, the California Division of Mines & Geology with 394 instruments, the U.S. Army Corps of Engineers with 356 instruments and the U.S. Geological Survey with 250 instruments. Some organizations, in addition to deploying strong-motion instruments, maintain their own instruments and provide their own data processing and archiving. These organizations may be considered to have complete strong-motion programs. The most notable of these are the programs of the U.S. Geological Survey and the State of California. Many other organizations rely on support from the U.S. Geological Survey and other sources for certain aspects of instrument service and data processing and archiving.

The Workshop was able to identify the owners and operators of approximately 2700 strong-motion accelerographs deployed nationwide. The combined annual instrumentation budget for all of the organizations identified is in excess of 3.5 million dollars. The average number of archived records obtained from the instruments identified is approximately 350 per year. Most of these records are from fairly low-level events, but frequently an event such as the Imperial Valley earthquake of 1979 will yield a large number of records of significant ground motion and structural response.

The majority of organizations deploying strong-motion instruments make their data available to outside organizations within a reasonable time after processing. Tables presented in Chapter 2 provide names of responsible individuals within each major organization deploying strong-motion instruments. These individuals may be contacted for further information on an organization's strong-motion activity or concerning the availability of strong-motion data.

It may be concluded that there is not, at present, an urgent need for the additional installation of isolated instruments for non-specific purposes. Future strong-motion installations should be undertaken selectively as part of a coordinated national program with well defined goals and objectives which are directed toward meeting specific data needs.

1.3 FUTURE NEEDS

Future strong-motion data needs generally fall into two categories: 1) the need for improved characterization of the ground motion resulting from an earthquake event and, 2) the need for improved characterization of the response of structures and other items to strong ground motion. These needs are perceived somewhat differently by earthquake engineers and seismologists, but both groups agree that a concerted, cooperative national effort is necessary if these needs are to be met.

The ground motion experienced at a given location depends both upon the nature of the earthquake's source mechanism and the factors affecting the propagation of waves from the source to the site. In order to gain a fuller understanding of the physical processes involved in this generation and transmission of seismic energy, it will be necessary to obtain data from fairly dense arrays of strong-motion instruments deployed within the near field region of strong earthquakes. These arrays should preferably be three-dimensional with instruments below the surface as well as on the surface. To date, there are essentially no near-field records from a great earthquake ($M > 7.8$).

Dense arrays of strong-motion instruments represent a substantial investment. Therefore such arrays should be located at sites with the highest possible expectation of the short-term occurrence of strong earthquakes. In addition, preference should be given to sites with well-known sub-surface structure, sites where a number of strong-motion instruments are already deployed and sites where simultaneous significant structural response studies could be conducted. Following these guidelines, three promising U.S. sites for cooperative ground motion and structural response studies have been identified. These are: the San Bernardino region, the Los Angeles Basin and the Hayward region of California. Other sites such as the Wasatch Valley area of Utah and the Imperial Valley and Parkfield regions of California are promising from the ground motion measurement point of view but are not as appealing for structural response studies.

Just as isolated instruments provide insufficient information to give a clear understanding of strong ground motion, so also, minimal code-type structural instrumentation provides inadequate information to give a clear understanding of structural response. What is needed are carefully thought through multiple-channel instrumentation systems designed to simultaneously measure the details of the free-field input, the soil-structure interaction and structural response. Only when data are available from such systems for a variety of different types and sizes of structures will it be possible to completely validate present soil and structural models and to make any significant improvements in code and design criteria.

A number of different types of structural systems should be instrumented in the regions identified as promising for cooperative studies. One- to four-story buildings of wood, steel, masonry and pre-cast panel construction should be instrumented as well as taller buildings of frame and shear wall construction. Accelerometers should be located so as to obtain data on translation, torsion, rocking and floor deformation. Devices should also be included for the measurement of inner-story displacement and overall structural displacement if possible. The structures instrumented should be representative of a cross-section of a particular type of structure weighted in proportion to the number of structures built of this particular type. All instrumented structures should have complete construction documentation available. In addition, pre- and post-event ambient testing is highly desirable.

Lifeline and other systems should be instrumented along with building structures. This should include highway bridges and overpasses, dams and other utility system facilities. The degree of instrumentation should be sufficient to obtain information equivalent to that for building structures.

In addition to the larger scale cooperative ground motion and structural studies outlined above, it is recommended that at least one strong-motion station be established in all U.S. population centers of 40,000 or more people in regions where damaging ground motion can reasonably be expected to occur within a 50 year interval.

Finally, it is recommended that a national mobile array of strong-motion instruments be established. This array should be capable of rapid deployment in the event of a major earthquake anywhere in the United States for the purpose of strong aftershock studies. Such aftershocks may have magnitudes greater than six and would provide extremely valuable ground motion and structural response data. A national mobile array could also be deployed in the event of a credible earthquake prediction anywhere in the United States.

1.4 PROCESSING, CATALOGING, ARCHIVING AND DISSEMINATION OF STRONG-MOTION DATA

Accurate and timely processing, cataloging, archiving and dissemination of strong-motion data are absolutely essential to the success of the data gathering programs mentioned above. Underlying the quality of strong-motion data is the accuracy of the transducer, signal conditioning and recording system. Each type of instrument deployed should be evaluated experimentally to determine its accuracy, linearity, frequency response, cross-axis sensitivity and temperature sensitivity. There is also a need for standardization and documentation of the procedures used to calibrate instruments prior to their deployment in the field.

The vast majority of strong-motion instruments currently deployed worldwide are of the analog-film recording type. Standard methods for processing analog film records have produced reasonable results for most engineering purposes. However, the conversion of film records into computer compatible format poses some problems. Current processing techniques are relatively slow and quality control of the digitization process is difficult to assess. In addition, recent research has uncovered possibilities for significant improvement in the areas of instrument correction and the handling of long-period information. There is a need to continually update processing techniques used for film records and it may be appropriate to reexamine some significant earlier records.

The deployment of reliable digital recorders may eliminate some of the major processing problems encountered with analog film recorders. The deployment of this type of instrument is encouraged. However, there are still a number of unanswered questions associated with this new instrument technology such as magnetic tape environmental and storage problems, electrical interference problems and dropouts. These questions can, no doubt, be resolved but they must not be overlooked. Furthermore, it is strongly recommended that standards be established for such instrumentation in order to assure both the accuracy and compatibility of the data obtained from instruments produced by different manufacturers.

The largest programs for archiving, cataloging and dissemination of strong-motion data are currently operated by the U.S. Geological Survey and the California Division of Mines & Geology. Many smaller organizations have made arrangements with one of these organizations to meet their particular needs. At the present time, the U.S. Geological Survey is the only U.S. organization maintaining a computer data base that can be accessed by outside users. This system, called SMIRS, contains limited information on earthquakes occurring primarily, but not exclusively, in the western hemisphere. The system is useful, but is not yet as comprehensive as needed.

Most oganizations deploying strong-motion instruments archive their own data and disseminate this data on request. There is generally no routine centralized cataloging or archiving of data. Some organizations, such as the U.S. Geological Survey, regularly send duplicate data to the Environmental Data Information Service of the National Oceanic and Atmospheric Administration (EDIS/NOAA) for archiving and dissemination. However, the number of instrument operators routinely sending data to this organization is relatively small.

There is concern that, as the number of participating organizations and the strong-motion data base continues to grow, a significant amount of data may not get into the hands of the user on a timely basis. Some of the major reasons for this problem are the fragmentation of existing programs, the lack of standards for documentation and the absence of a comprehensive catalog of strong-motion data. It is strongly recommended that minimum standards of documentation be adopted and that strong-motion data be archived and cataloged so that it is readily available to users worldwide. The programs operated by the U.S. Geological Survey and EDIS/NOAA could provide the basis for an expanded National Cataloging and Archiving Service.

1.5 PROGRAM MANAGEMENT AND FUNDING

The deployment and maintenance of strong-motion instrumentation involves some special problems for management and funding. Due to the potentially long time periods that may elapse before significant data are obtained from a given site, stability of both management and funding is of the utmost importance.

Each of the organizations maintaining strong-motion instruments has its own particular interest in the earthquake hazard and its instruments are deployed so as to maximize the information obtained relating to these interests. The effectiveness of these individual programs could be substantially improved through greater cooperation and coordination between the various concerned groups. However, a number of these organizations have had long experience in the field, are well organized, and well financed and would find it impractical to turn over their basic responsibilities to any central agency. Therefore, at the present time it does not appear feasible to establish one central organization of any type as the headquarters for a U.S. national strong-motion program.

At the same time, it would be a definite advantage if those organizations engaged in strong-motion instrumentation in the United States could be viewed as parts of a National Strong-Motion Program. It is believed that this can be best accomplished by the formation of a National Committee on Strong Earthquake Motions. It is therefore recommended that the Universities Council for Earthquake Engineering Research and the Earthquake Engineering Research Institute jointly create such a National Committee.

The primary objective of the National Committee on Strong Earthquake Motions would be to develop and maintain a national strong-motion program plan which would provide for the participation of all organizations involved in the recording of strong earthquake motions and in the processing, archiving and dissemination of strong-motion data. This would involve: 1) the formulation of objectives which support the various needs of research workers, engineering designers, government agencies and others, 2) the organization of workshops, seminars, etc., on strong motion in order to develop appropriate priorities, 3) the development of a plan to assure that appropriate catalogs of strong-motion data were prepared, that data was archived in a timely and accessible manner, and that periodic reviews of data processing methods were undertaken, and 4) the providing of advice to public and private organizations on policies and programs related to strong ground motion.

At the present time, the National Science Foundation has been given responsibility for funding a major national strong-motion program, with operation and management responsibility for this program assigned to the U.S. Geological Survey. This division of responsibilities has created certain organizational and management problems which have inhibited the optimum development of this program. It is recommended that immediate action be taken to resolve these problems. Possible alternatives and a specific proposal are contained in Chapter 5.

It is anticipated that the cost of strong-motion programs will increase rapidly in the future. The relatively informal way in which these programs have been supported in the past will clearly no longer be adequate in light of the importance of the subject. The ultimate beneficiaries of strong-motion data are the citizens of the United States. It is therefore important that present levels of federal funding for strong-motion programs be maintained and, if practical, increased. Many of the principal users of strong-motion data make no significant contributions to the support of this program. This includes research organizations and industry groups as well as some federal, state and local government agencies. It is recommended that a vigorous effort be made to increase the level and diversity of funding for the U.S. strong-motion instrumentation program.

One of the most effective strong-motion programs from the point of view of both management and funding is the program conducted by the State of California. Many features of this program might be adaptable to conditions in other states or municipalities. It is therefore recommended that states and local municipalities in zones of high seismic risk examine the program of the State of California to determine the extent to which this program might be adapted or modified to meet their particular needs.

1.6 CONCLUSIONS

The U.S. strong-motion program will celebrate its 50th anniversary in 1983. This program has already made a significant contribution to the fields of earthquake engineering and seismology. However, much remains to be accomplished. With new instrumentation, and more powerful and sophisticated computing machinery, many of the unrealized goals of the strong-motion program are now within reach. These goals can be met, but it will require a rededication on the part of all those involved in the operation, management and funding of tho U.S. program. There is every indication that this will be accomplished.

CHAPTER 2

EXISTING STRONG-MOTION PROGRAMS

2.1 INTRODUCTION

An International Workshop on Strong-Motion Earthquake Instrument Arrays was held in Hawaii in May 1978 (Iwan, 1978). The goal of this International Workshop was to develop a workable plan for the possible future deployment of dense strong-motion earthquake instrument arrays with primary emphasis on ground motion studies. In April 1980, a workshop was held in San Francisco, California for the purpose of 1) reviewing existing building strong-motion instrumentation programs, 2) documenting existing procedures for processing and interpreting data from those programs, and 3) identifying ways to improve data acquisition, analysis, and interpretation techniques for use in the design of engineering structures (Hart, 1980). Meanwhile, a 1980 Panel on National, Regional, and Local Seismograph Networks drafted a report (Bolt, 1980) as the "first attempt by the seismological community to rationalize and optimize the distribution of earthquake observatories across the United States." The report resulted from several meetings of the Panel over a three-year period. The above-mentioned proceedings and reports provide valuable reference material for the subject matter of this chapter.

Prior to this U.S. National Workshop, a Strong-Motion Earthquake Instrumentation Survey questionnaire was mailed to all organizations known to be operating strong-motion instruments. A copy of the survey questionnaire is contained in Appendix A of this report. The responses to the survey are summarized in this chapter. Because the survey distribution may not be exhaustive and since some organizations chose not to respond, the summarized data are not complete. It is also realized that the same questions can be interpreted in different ways, and that answers are subject to various interpretations. Moreover, the very process of making a summary necessarily implies a loss of detailed information. Nevertheless, it is felt that the information presented gives a good picture of the U.S. strong-motion program. To obtain more accurate and complete information, the reader is encouraged to contact the organization in question directly. For this purpose, a list of responding organizations and respective contact persons is given in Appendix B of this report.

2.2 SUMMARY OF STRONG-MOTION PROGRAMS

Responses to most items of the survey are summarized in Table 2.1. Since some of the survey responses do not lend themselves to tabular form, a supplementary text is provided in Section 2.3. In addition, a brief summary of some programs not included in Table 2.1 is given in Table 2.2. Section 2.3 and Tables 2.1 and 2.2 should be considered together.

2.3 SUPPLEMENTAL COMMENTARY

Goals & Objectives of Strong-Motion Programs

Instrumentation programs vary in their objectives from organization to organization. Program objectives arise from several sources including statutory mandates, building code provisions, need for specific seismic data, concern with regard to the response of specialized structures, and earthquake prediction. Some of the more important objectives for the acquisition of strong-motion earthquake data are considered in the following paragraphs. The abbreviations of the organizations indicated are listed in Table 2.3

Statutory mandates. Under state law, certain governmental agencies have been directed to instrument representative structures on geologic sites throughout the State of California, to process the records and to distribute the data to interested users (CDMG, USGS).

Building code programs. The assessment of structural damage sustained by a structure during an earthquake, especially for a high-rise building, is very difficult. Therefore, cities have approved programs to instrument tall buildings to obtain this type of information (CLA, CSF). The documentation also serves as an aid in demonstrating the post-earthquake condition of buildings to the owners.

Need for seismic data. Presently, there are many questions about earthquake ground motion for which answers are not available. More strong-motion data from earthquakes occurring near subduction zones are needed (LDGO). Subduction zones occur in the circum-Pacific belt such as in the Aleutian Arc, Mariana Trench, Philippine Plate, etc. More seismic information on the behavior of large dams is needed since the destruction of dams may have severe consequence to the structures and population downstream (LADWP, LACFCD, USACE, CDWR, PGE, USBR).

Information on the actual behavior of lifeline structures during earthquakes is important to structural designers (LADWP, MWDSC). Instrumentation in the past has not yielded information on torsional response, soil-structure interaction (EPRI) and individual structural member behavior (EBMUD). Seismic data on the behavior of buried and underground utilities are scarce. Finally, site-specific ground motion information for engineering design of structures including lifelines is always needed (SCEC, USC, DOE).

Specialized structures. Owners of large lifeline structures such as power generation plants (SCEC, LADWP, SDGE, PGE) and bridges (FHWA) have a clear interest in the performance of these structures in a large earthquake. Furthermore, governments have critical or unique facilities that must be functional af-er a disaster. Structural response information on the behavior of these structures and facilities is needed for establishing future design criteria or for retrofitting existing similar structures at other installations not yet subjected to potential earthquakes (NCEL).

Earthquake prediction. Scientific prediction of earthquake occurrence is still in its infancy. Information is needed about the nature of source mechanism for large earthquakes. This type of information can only be obtained from dense arrays of free-field strong-motion accelerographs located in high seismic regions (UCSD, SUNYBI).

Data availability. On the survey, organizations were asked to indicate how soon after an earthquake data was available for distribution. The responses varied from a few days to 18 months. Some data may be made available in a preliminary form for easy access sites within a few days of the event while a complete report can take many months.

The process for gathering and reporting the data is generally as follows:

1) Collection of data from field stations (local and remote)
2) Initial processing
   a) Optical-mechanical type - develop film
   b) Tape type - convert analog & digital to hard copy
   c) Prepare identification labels
   d) Make identical copies for archival purposes
   e) Determination of preliminary peak acceleration, response duration, frequency, etc.
   f) Publication
3) Secondary processing for significant events only
   a) Digitization of optical-mechanical records
   b) Reproduction of computer-compatible tape for magnetically recorded records
   c) Determination of uncorrected and corrected time histories
      i) acceleration-time
      ii) velocity-time
      iii) displacement-time
   d) Determination of response spectra
      i) response spectra
      ii) Fourier spectra
      iii) response duration spectra
   e) Publication

Use of strong-motion data by deploying organization. Strong-motion data provide the basis for 1) analysis of the validity of present analytical design methods, 2) evaluation of the performance (integrity) of existing structures, and 3) design criteria for new structures and modifications to existing structures. This data also provide a means for the systematic study of wave propagation, strong ground motion attenuation and modification, earthquake source parameters and aftershock migration. In addition, it may be used to investigate nonlinear structure and soil-structure interaction behavior.

Some organizations have special uses for strong-motion data, such as: 1) the extraction of peak and spectral values for hazard mapping in the Outer Continental Shelf Environmental Assessment (Alaska) Program, 2) dam safety monitoring, 3) post-earthquake performance reports to organizational management and regulatory agencies, and 4) inversion analysis of the Los Angeles Basin crustal structure to determine ground motions for the engineering design of structures.

Future plans. The survey questionnaire gave organizations the opportunity to indicate any plans they might have to change the direction of their strong-motion activity in the future. Those respondents indicating no plans to change direction in the immediate future include CDMG, CDWR, FHWA, LADWP, LACFCD, EBMUD, MWDSC, PGE, SDGE, SCEC, SUNYBI, USACOE, and USBR. One major change in direction was reported by the City of Los Angeles. A proposed code change would require only one instrument per building, instead of three, which would result in a significant change in the strong-motion program of that city. Another change in direction was reported by The Electrical Power Research Institute which plans to discontinue simulation studies.

2.4 CURRENT DATA PROCESSING FACILITIES

To be useful to the scientific and engineering community, significant accelerograms from film records must be converted to a digital format. At present, there are three organizations which have a capability to digitize records semi-automatically. These are:

1. IOM Towill. A laser line following device is used. This system is used by USGS.

2. University of Southern California. A fast scan photodensitometer is used.

3. California Division of Mines and Geology. This system is essentially the same as the USC system.

TABLE 2.1

SUMMARY OF U.S. STRONG-MOTION PROGRAMS

Name of Organization (Contact)	Established Deployment Strategy	Procedure For Selection of Sites	Install. By	Maint. By	Present No. of Instruments [Next Years Additional Instruments]	Yearly No. of Records Archived	Procedure for Record Processing	Records Processed By	Location of Archived Data	Availability of Data (Cost)	Approximate Annual Budget	Source of Funding
Calif. Dept. of Transportation (J. Gates)	Instrument transportation structures.	Based on seismicity, structure and representa-tiveness.	Own staff (past) CDMG/USGS (current)	Own staff and CDMG/USGS	3 on bridges	1 or 2		Own staff plus CDMG	Caltrans, CDMG	Contact Caltrans	200	FHWA
Calif. Dept. of Water Resources (P. Morrison)	Instrument all principal structures, dams, pumping, & power plants.	Design engineers.	Own staff	Own staff (Some USGS)	60 instruments	~2	USGS procedure	USGS	USGS (film)	Contact USGS	0	State water project funds
Calif. Div. of Mines & Geol. (T.M. Wootton)	Obtain significant records, free-field, arrays, structures, & lifelines.	Site-selection recommended by CDMG committee, reviewed by staff members.	Own staff	Own staff	394 instruments 344 stations; 65 RTS,* 180 with real time. [35 instr.]	200 computer processed.	Digitizing, computing, plotting, using USC procedure.	USGS ('72-'77) CDMG ('77-)	CDMG (magnetic tapes)	On request ($25+)	1,200,000	Building permit fees
Columbia Univ. Lamont-Doherty Geol. Observ. (K. Jacob)	Capture great event (M8) in seismic gap. Seismic source & wave propagation study.	Prefer hardrock sites away from man-made struc-tures.	Own staff	Own staff + Kinemetrics (Lab-over-haul).	18 instruments Alaska - 10 New York - 3 Carib. - 5 [5-6 instr.]	~2 (quiescent stage of seismic gaps).	No standard procedure.	Hand digiti-zation, USGS or commer-cial firms.	LDGO/USGS	LDGO/USGS On request	35,000	USGS BLM/NOAA-/OCSEAP NSF
Dept. of Energy Las Vegas (J. Blume)	Record underground nuclear explosions and some earthquakes.	Fixed instruments in building. Mobile ground stations.	URS/Blume Engrs.	URS/Blume Engrs.	20 fixed sites 60 mobile instr. Mobile with real time.				URS/Blume Engrs.			DOE

TABLE 2.1 CONTINUED

Name of Organization (Contact)	Established Deployment Strategy	Procedure For Selection of Sites	Install. By	Maint. By	Present No. of Instruments [Next Years Additional Instruments]	Yearly No. of Records Archived	Procedure for Record Processing	Records Processed By	Location of Archived Data	Availability of Data (Cost)	Approximate Annual Budget	Source of Funding
Dept. of Energy San Francisco Oper. Office, ETEC Office (R.E. Fenton)	Monitor ground excitation and structural response.	ETEC Engrs. with outside consultant.	Own staff plus consultant.	USGS	6 instruments	(3 since 1974)		USGS	USGS	USGS	3,000	DOE
East Bay Municipal Utilities District (J. Gilbert)	To have key structures included in the Calif. program.	Consider typical structures and sites, known active faults, etc.	CDMG	CDMG	4 instruments [4 instr.]			CDMG	CDMG	Contact CDMG	25,000	EBMUD
Federal Highway Administration (J.D. Cooper)	Define characteristics of seismic forces on bridges.	In cooperation with state highway depts. & USGS.	USGS or private contractor.	USGS or private contractor.	30 instruments 2 RTS*	1 or 2	USGS/CDMG	USGS/CDMG	USGS/CDMG	Contact CDMG	>10,000	FHWA
Idaho Natl. Engr. Lab. (J.J. King)	Instrument critical reactor facilities for analyzing structural response.	Critical INEL site facilities.	USGS (past) Own staff (current)	Own staff	15 instruments	No records as yet.		Own staff		Contact USGS	20,000	DOE
Lawrence Livermore National Laboratory (A.F. Shakal)	Instrument important and/or complex structures.	In consultation with USGS	Own staff	Own staff complemented by equipment supplier.	4 instruments		Being developed.	Own staff	To be established	Will probably notify and send copies to USGS		DOE
Los Angeles City, Dept. of Building & Safety (J.O. Robb)	Code specifies buildings > 6 stories/60,000 sq ft - structural response study.	Based on code required structures.	USGS (past) Commercial (current)	City Electrical Test Lab.	486 instruments 160 bldgs. [40-50 instruments]			Owners; USGS; Caltech; UCLA; Kinemetrics	Record processor	Contact processor or bldg. owner	20,000	Primarily building owners

TABLE 2.1 CONTINUED

Name of Organization (Contact)	Established Deployment Strategy	Procedure For Selection of Sites	Install. By	Maint. By	Present No. of Instruments [Next Years Additional Instruments]	Yearly No. of Records Archived	Procedure for Record Processing	Records Processed By	Location of Archived Data	Availability of Data (Cost)	Approximate Annual Budget	Source of Funding
Los Angeles City, Dept. of Water & Power (L. Lund - L. Escalante)	Existing & new major facilities in regions of known faults.	Engineers & geologists. Data for seismic analysis and design.	Own staff & CDMG	Own staff	35 instruments 1 RTS* 42 seismoscop. [9 instr. (3 replacement)]	2	CDMG	Own staff & CDMG	LADWP (USGS pre-1975)	Contact LADWP	>5,000	LADWP
Los Angeles County Flood Control District (M. Johnson)	Place instruments on major dams where greatest information can be obtained in shortest time.	Based on Public hazard, uniqueness of design, learning quotient, future status of structure.	CDMG	CDMG	25 instruments 5 dams [3 instr. (replacement)]		CDMG	Caltech (past)	Caltech (past)	Contact LACFCD/ CDMG		CDMG building fees
Metro. Water District of So. Calif. (G.F. Horowitz)	Instrument important facilities throughout So. Calif.	Consultation between USGS and MWDSC engineering personnel.	USGS (with support of MWDSC).	USGS	24 instruments 1 RTS* [2 instr. (replacement)]				USGS	Contact MWDSC	15,000	MWDSC
Pacific Gas & Electric Co. (O. Steinhardt)	NRC + other requirements.	Staff judgement.	Own staff	Supplier & own staff	91 instruments 8 sites [2 instr.]	5	USGS	USGS	PG&E	PG&E On request	35,000	PG&E
Sacramento Municipal Utility District (R. Deguichi)	Comply with NRC regulations.	Nuclear facilities only.	Own staff	Own staff	6 instruments [18 instr.]			Supplied by contract	SMUD	SMUD On request	600,000	SMUD
San Diego Gas & Electric (J.C. Burton)	Selective locations to supplement other programs.	Staff judgement.	CDMG/USGS (present) Own staff (future)	CDMG/USGS (present) Own staff (future)	2 instruments [1 instr.]	1	CDMG/USGS	CDMG/USGS	SDGE/CDMG/ USGS	CDMG/USGS		SDGE

TABLE 2.1 CONTINUED

Name of Organization (Contact)	Established Deployment Strategy	Procedure For Selection of Sites	Install. By	Maint. By	Present No. of Instruments [Next Years Additional Instruments]	Yearly No. of Records Archived	Procedure for Record Processing	Records Processed By	Location of Archived Data	Availability of Data (Cost)	Approximate Annual Budget	Source of Funding
Southern California Edison (T.A. Kelly)	Optimum area coverage + diversity of facilities & equipment.	Where site specific information is desired.	Own staff or equip. supplier	Supplier	26 instruments Includes one RTS* with 6 triaxial sensors	4	Strip chart + digitized records, time histories & spectra	Own staff	SCE	SCE	14,000	SCE
Stanford Univ. (H.C. Shah)	Obtain seismic loading information for campus structures.	Based on proximity of buildings and geotechnical data.	USGS	USGS	1 instrument	15		Own staff	Stanford Univ. Blume Center	Stanford On request	5,000	Stanford Univ.
State of Wash. Dept. of Trans. (U. Vasishth)	To assist in the refinement of design practice.	Recommendations from FHWA & USGS.	USGS	USGS	90 instruments					WSDOT On request	15,000	FHWA WSDOT
State Univ. of New York at Binghampton (F.T. Wu)	Study path & local effects in meizoseismal areas.	Near sites of historical strong earthquakes.	Own staff	Own staff	4 instruments [4 instr.]		Being developed	Own staff	SUNY	SUNY On request	700	NSF + NY State
Tacoma City, Washington, Public Works Dept., Bldg. Div. (C.A. Pearson)	Instrument poor soil areas, and normal buildings.	Chosen by subcommittee of Board of Building Appeals.	--------	Own staff	Planning stage; no instruments installed.						Not yet established	Surcharge on bldg. permits
Union Carbide Corporation - Nuclear Div. (J.E. Beavers)	To monitor strong-motion that might damage plant facilities.	Based on economic or safety considerations.	Own staff	Own staff	5 instruments [30 instr.]		Own staff	Own staff	Own staff	On request		DOE

TABLE 2.1 CONTINUED

Name of Organization (Contact)	Established Deployment Strategy	Procedure For Selection of Sites	Install. By	Maint. By	Present No. of Instruments [Next Years Additional Instruments]	Yearly No. of Records Archived	Procedure for Record Processing	Records Processed By	Location of Archived Data	Availability of Data (Cost)	Approximate Annual Budget	Source of Funding
U.S. Army Corps of Engineers (R. Ballard – F. McLean)	Most critical structures in areas of seismic hazards.	Minimum 2 instruments, crest-abutment. Up to 7 on larger dams.	USACE/-USGS	USACE/USGS	356 instruments 74 seismoscope 102 sites [50 instr.]	6	USGS	USGS	USGS	Contact USACE, USGS		USACE
U.S. Bureau of Reclamation (A. Viksne)	Evaluate structural integrity, and obtain design information.	Potential hazard; seismic zones 3 & 4; proximity to tectonic features with potential strong ground motions.	USGS (with assist. of USBR)	USGS (past) Own staff/ USGS (1982–)	68 instruments 1 RTS*		USGS	USGS	USGS	USGS	140,000	USBR
U.S. Geological Survey (R. Borcherdt)	Develop special ground and structural arrays in active regions.	Based on historic seismicity & typical structures.	Own staff	Own staff	250 sites owned 125 real time 1-18 chan. RTS* Varying resp. for 750 sites owned by other agencies.	95 all sources	Digitized using laser scan, processed and analyzed.	USGS	USGS & EDIS/NOAA Data Center	Film cps. (minimal) Digital magnetic tape ($100) via EDIS	1,350,000 (670,000 for maint. of owned sites)	NSF + other Federal agencies served
Univ. of Alaska Geophysics Institute (H. Pulpan)	Instrument seismic gaps.	Identification of promising free-field sites; preferably rock.	Own staff	Own staff	8 instruments			USGS or commercial company	Univ. of Alaska	Univ. of Alaska On request	20,000	NOAA (OCSEAP)
Univ. of Calif. at San Diego with Universidad Autonoma de Mexico (UNAM) (J.G. Anderson)	Instrument free-field sites for seismic source and wave propagation studies.	Based on high probability of yielding important data.	Own staff	Own staff	21 instruments 5-8 for aftershock studies. All with real time.	6		Own staff	UCSD	UCSD On request	5,000	NSF

TABLE 2.1 CONCLUDED

Name of Organization (Contact)	Established Deployment Strategy	Procedure For Selection of Sites	Install. By	Maint. By	Present No. of Instruments [Next Years Additional Instruments]	Yearly No. of Records Archived	Procedure for Record Processing	Records Processed By	Location of Archived Data	Availability of Data (Cost)	Approximate Annual Budget	Source of Funding
Univ. of Nevada at Reno (B. Douglas)	Monitor strong-motion & structural response in western Nev.	Advisory Committee.	Own staff	Own staff	15 instruments		No data yet.				800	FHWA 1/4 UNR 3/4
Univ. of So. California (T. Teng - M.D. Trifunac)	Instrument free-field sites of important geological & seismological significance.	Based on geographic distribution and power availability.	Own staff	Own staff	81 instruments All with real time.		Digitized using light scan, then processed and analyzed.	Own staff	USC/USGS (70 mm film)	USC On request	~ 50,000 Maint. & develop-mental research	NSF
Univ. of Wash. (S.W. Smith)	Elimination of gaps in Wash. S-M network.	Instrument free-field rock sites.	Own staff	Own staff	4 instruments				To be archived with USGS			
Veterans Administration (R. McConnell)	Instrument all critical areas and some other areas where there are inadequate records.	VA Hospital Centers.	NOAA (past) USGS (current)	USGS	66 instruments 56 stations			USGS				VA

*RTS - Remote transducer system, analog or digital.

TABLE 2.2

SUPPLEMENTAL LIST OF ORGANIZATIONS CONDUCTING STRONG-MOTION INSTRUMENTATION PROGRAMS*

NAME OF ORGANIZATION (Contact)	SUMMARY
General Services Administration (B. Spence)	3 accelerographs (building)
Tennessee Valley Authority (R. Barnett)	3 accelerographs in each of three nuclear power plants
California Inst. of Technology (R. Relles)	15 sites including 3 RTS (buildings)**
University of Calif., Berkeley (B. Bolt)	8 sites including 2 RTS (downhole)**
Massachusetts Inst. of Technology (R. Whitman)	1 accelerograph
University of South Carolina (P. Talwani)	"several" mobile digital recorders (strong/weak motion)
Seattle Light & Power (G. W. Bishop)	2 accelerographs (dam)
California Department of Transportation (J. Gates)	RTS on 3 bridges** 2 accelerographs (bridge)
Vallecitos General Electric (N. F. Fifer)	At least 1 accelerograph
San Francisco Bay Area Rapid Transit District (J. Casey)	4 accelerographs in trans-bay tube
Marin County Water District (D. Grundman)	2 accelerographs (dam)

TABLE 2.2 (CONTINUED)

NAME OF ORGANIZATION (Contact)	SUMMARY
United Water Conservation District, California	1 accelerograph (dam)
Non-code Building Owners, San Francisco	5 buildings in San Francisco
California State University, Northridge (H. Adams)	2 accelerographs (1 building)
California State University, San Jose (J. Brooks)	3 accelerographs (1 building)
University of California, Los Angeles (G. Hart)	36 accelerographs (12 buildings) 1 RTS (building)**
Nuclear Regulatory Commission (Power plant owners)	Operating Nuclear Plants - At least 62 plants were instrumented by Kinemetrics. An unknown number of others were instrumented by United Electrodynamics, Teledyne-Geotech, or Terra Technology
International Conference of Building Officials (ICBO). Code required instrumentation in buildings.	321 accelerographs (107 buildings - 44 communities) were installed in ICBO code-buildings by the USGS before withdrawing from this responsibility in 1976. There are an estimated 250 buildings instrumented under ICBO code. A partial listing of the location of accelerographs is given below.

Alhambra	1	Norwalk	2
Bakersfield	3	Oceanside	1
Berkeley	2	Orange	3
Beverly Hills	16	Oxnard	1

TABLE 2.2 (CONCLUDED)

NAME OF ORGANIZATION (Contact)	SUMMARY			
ICBO (Continued)	Burlingame	1	Palo Alto	3
	Coronado	8	Pomona	1
	Culver City	3	Riverside	1
	El Segundo	5	San Bernardino	1
	Emeryville	2	San Bruno	1
	Fremont	1	San Dimas	1
	Fullerton	2	San Mateo	2
	Garden Grove	1	San Rafael	1
	Glendale	2	Santa Ana	6
	Hayward	1	Santa Clara	2
	Inglewood	4	Santa Maria	1
	Irvine	1	Santa Monica	3
	Laguna Hills	3	Santa Rosa	3
	Laguna Niguel	1	Torrance	2
	Long Beach	1	West Covina	1
	Marina del Rey	1	Whittier	1
	Menlo Park	1	Reno	1
	Newport Beach	8	Anchorage	1
	All cities in California except Reno, Nevada and Anchorage, Alaska.			

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*Insufficient information for inclusion in Table 2.1.
**RTS - Remote transducer system, analog or digital.

TABLE 2.3

ABBREVIATIONS

BLM	Bureau of Land Management
CDMG	California Division of Mines & Geology
CDWR	California Department of Water Resources
CLA	City of Los Angeles
CSF	City & County of San Francisco
DOE	Department of Energy
EBMUD	East Bay Municipal Utility District
EDIS	Environmental Data Information Service
EPRI	Electrical Power Research Institute
ETEC	Energy Technology Engineering Center Project Office, Department of Energy
FHWA	Federal Highway Administration
LACFCD	Los Angeles County Flood Control District
LADWP	Los Angeles City Department of Water & Power
LDGO	Lamont-Doherty Geophysical Observatory, Columbia University
MWDSC	Metropolitan Water District of Southern California
NCEL	Naval Civil Engineering Laboratory/Facilities Engineering Command
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
OCSEAP	Outer Continental Shelf Environmental Assessment Program
PGE	Pacific Gas & Electric Company
SCEC	Southern California Edison Company
SDGE	San Diego Gas & Electric
SMUD	Sacramento Municipal Utilities District
SUNYBI	State University of New York at Binghampton
UCSD	University of California, San Diego
UNR	University of Nevada, Reno
USACE	U.S. Army Corps of Engineers
USBR	United States Bureau of Reclamation
USC	University of Southern California
WSDOT	Washington State Department of Transportation

CHAPTER 3

FUTURE NEEDS

3.1. INTRODUCTION

The ultimate goal of present and future strong-motion instrumentation is to obtain data that can be used to improve the design of safe and economical structures. It is recognized that engineers and seismologists have complementary approaches to achieving this goal. The approach taken by the structural engineer is to develop a better understanding of the relationship between the earthquake ground motion and the behavior of the structure up to, and through the damage range. The approach taken by the seismologist is to develop a better understanding of the basic mechanisms which produce strong ground motions and to distinguish among the various influences along its path to becoming the input driving force into a structure. Future needs in strong-motion instrumentation can and should provide a balanced level of effort between (1) the study of structural response, and (2) study of seismic source and propagation paths, including the soil-structural system. The implementation of such a balanced approach will provide a significant increase in the understanding of earthquake-induced response and significantly improve the protection of life and property.

The following sections address the future needs conceived jointly by structural engineers and seismologists. These needs are: (1) the needs for the characterization of structural response, and (2) characterization of the strong-motion input to the soil-structure system and the soil-structure system response. A cooperative strong-motion instrumentation effort in selected fault zones in the U.S. is essential to answer these needs. These fault zones are selected to provide both sufficient coverage of representative structures and the potential for significant source and path studies in the near future. Finally, there is a need for a cooperative pilot mobile strong-motion instrumentation program.

3.2. NEEDS FOR THE CHARACTERIZATION OF STRUCTURAL RESPONSE

Past efforts have concentrated on the area of ground motion instrumentation as a logical first step in understanding the earthquake hazard. Structural engineers support this approach and benefit from the results obtained as a result of such activity. Today, numerous strong ground motion stations exist which provide basic, though not always completely adequate coverage of the areas of highest seismicity and structural engineering interest in the U.S. Therefore, an augmented strong-motion instrumentation program should now consist of a balance between instrumentation programs aimed at ground response and those directed toward structural response.

Instrumentation currently in place and intended to provide structural response data is of three basic types: a ground level instrument in or near a building, code type instrumentation, and remote accelerometer-central recording instrumentation. Ground level instrumentation provides only basic triaxial strong-motion records at or near the base of a structure. Code-type instrumentation provides normally a triaxial response package at the ground, mid-height, and roof levels. It provides basic ground motion data and limited structural data useful in identifying potential structural damage. Code-type instrumentation does not provide sufficient detail to characterize structural response. Central recording instrumentation consists of remotely placed accelerometers connected by cable to one or two multi-channel recorders. The accelerometers are selectively placed to collect response data sufficient to characterize ground motion as experienced in the base of the structure, and structural response including overall translational and torsional motion as well as local motions in floor diaphragms, tall exterior walls, etc.

Today, as a result of efforts in California, strong-motion records have been obtained from numerous structures. Experience in attempting to interpret these records has clearly shown that while a single nearby ground motion record is better than no record and while code-type instrumentation provides very basic structural data, only a carefully thought out, multiple channel, central recording system provides data for the detailed characterization of structural response. To date only a handful of centrally recorded data sets have been obtained and can be used for the evaluation of structural response. Only the set recorded from the Imperial County Services Building provides data in the damage to collapse range of structural response. The rest represent primarily pre-damage response generally in the elastic range. Given the vast number of types and sizes of buildings in seismically active regions, it is obvious that we have only begun to record structural response suitable for use in the validation of structural models and improvement of structural design.

Laboratory structural testing, analysis, and design techniques have rapidly developed over the past 15 years. This is evident in the dramatic changes in the state-of-the-art of building design techniques that have occurred especially since the 1971 San Fernando earthquake. Because of this evolution of understanding and the fact that the useful life of a structure often exceeds 50 years, the majority of existing buildings have been designed, detailed and constructed under pre-1970 standards. In many cases, these structures are considered by engineers to be unsafe. Strong-motion structural response data must be obtained for older buildings for which there is the potential for major financial and life loss.

For the reasons stated, the future needs of strong-motion instrumentation in structures must be aimed at providing a balanced level of effort for obtaining data supportive of (1) approaches used for hazard evaluation of existing structures, and (2) studies to improve engineering design practice for future structures. The needed strong-motion data must be obtained starting at the damage level and carrying on up to collapse level of structural response. This data is needed so that a correlation can be made between damage observed, levels of motion recorded, levels of forces indicated by dynamic structural analysis, and building performance and code-based assumptions. Life safety and the economics of design versus damage can be addressed with such data to achieve two goals. One must be aimed at providing minimum information at all locations with a significant number of engineered structures. The other should be aimed at providing detailed response data for a representative sample of structural types and designs. The following two specific needs are therefore identified:

1. At least one ground motion (free-field) site needs to be established in all population centers of 40,000 or more where damaging ground motion can be expected to occur in the next 50 years.

2. Structural response data is needed to quantify the force-displacement relationship (including damping and ductility) for the lateral force resistant system for the entire structure and its soil-structure interaction characteristics.

The selection of specific structures to be instrumented should represent a cross section of all types of structures and should be weighted in proportion to the number of structures built of that type and function. Buildings should be instrumented in regions of the United States that have significant seismic exposure and in which records can be expected within the useful life of the instrumentation. For completeness, all buildings instrumented must have complete construction documents available including calculations, design criteria, architectural and structural drawings, specifications and test reports. In addition, pre- and post-event ambient vibration studies would provide useful additional information and should be performed when possible.

In order to properly obtain the kind of detailed response data needed, a minimum level of instrumentation is required as follows:

1. Strong-motion accelerograph systems in buildings should be located in order to obtain data on building translation and torsion (including mode shapes), rocking motion (overturning), floor load distribution (in-place bending) and overall base input motion.

2. Strong-motion instrumentation should include devices for measuring inter-story displacements and overall structural displacements directly. The use of scratch gauges or specific displacement measuring devices is encouraged.

3. Accelerographs should be located at near free-field ground sites adjacent to each instrumented building.

The following one to four story building types should be instrumented:

1. <u>Wood diaphragm shear wall buildings (concrete and masonry)</u> - Floor diaphragm deformation, out-of-plane deformation of shear walls, relative ground level deformations, and overturning.

2. <u>Steel moment frame, concrete ductile frame, and concrete non-ductile frame buildings with concrete or metal deck floor systems</u> - Interstory displacements including orthogonal effects, and axial deformations.

3. <u>Concrete and masonry shear wall buildings with concrete or metal deck</u> - Overturning and diaphragm deformations.

4. <u>Precast panel buildings</u> - Force deformation behavior of joints.

The buildings in this category should be located within 10 km of an active fault.

Five- to twelve-story buildings should be instrumented according to building type as follows:

1. <u>Frame buildings (steel and concrete)</u> - Interstory displacements including orthogonal effects and axial deformations.

2. <u>Shearwall buildings (steel with braced frame, steel with concrete shear wall, concrete with concrete shear walls, and masonry bearing and shear walls)</u> - Interstory displacements including orthogonal effects and axial deformations.

The buildings in this category should be located within 25 km of an active fault.

Buildings over twelve stories in height should be instrumented with each of the building types listed instrumented to quantify the noted items:

1. Frame buildings (steel) - Interstory displacements including orthogonal effects and axial deformations.

2. Shearwall buildings (steel with concrete shear walls and steel with braced frame).

The buildings in this category should be located within 150 km of an active fault.

3.3. NEEDS FOR THE CHARACTERIZATION OF STRONG MOTION INPUT AND SOIL/STRUCTURE SYSTEM

A need for design is the characterization of ground motions at a site. This characterization can be given in many ways, such as peak motions, response spectra, or time histories of the strong ground motion at a site with confidence limits, particularly in areas close to damaging earthquakes. No strong-motion recordings exist for truly great earthquakes. Furthermore, little information exists about the details of high frequency motions near faults; motions that may show significant variations due to the interaction of the fault rupture and the propagating waves. Another uncertainty is the data scatter in ground motion parameters. For example, the coefficient of variation of the peak acceleration as a function of epicenter distance is about two. In order to reduce these and other uncertainties, a number of different types of arrays are needed. These range from fixed to mobile arrays. Discussions of the problems to be addressed by each array and general array design considerations follows.

3.3.1 FIXED SURFACE ARRAYS

To date, strong-motion records from a truly great earthquake ($M > 7.8$) have not been obtained. Yet, such great events are potentially the most devastating earthquakes because of their damaging effects on structures from sustained strong shaking, and because of the effects from ground failure or liquefaction in unconsolidated soils. Accurate ground motion records from great earthquakes are urgently needed for engineering purposes as well as seismic source studies. If ground motion data from a few great events become available, it may be possible to devise scaling laws to be used in predicting the ground motion from great events using smaller events.

In recent years the concept of seismic gaps has shown considerable success in forecasting the sites and approximate magnitude of large and some great earthquakes at simple plate boundaries. The basic idea is that those segments of an active plate boundary that broke in a great earthquake a short time ago are less likely to break again soon, whereas a segment which has not broken for a long period, comparable to the average recurrence time, is likely to break soon. Observation has shown that these soon-to-break segments are often characterized with a nearquiescence in background seismicity relative to adjacent segments that ruptured more recently; hence the term 'seismic gap'. Within the last two decades about a dozen of the several dozen known seismic gaps ruptured by large or great earthquakes shortly after their identification as gaps.

Several unruptured seismic gaps are believed to have been clearly identified in the U.S. and abroad. It therefore appears possible to obtain strong-motion records from a truly great earthquake within one or two decades if a few of these gaps are instrumented with fixed surface arrays of a sufficient number of strong-motion recorders. The instrumentation of clearly identified seismic gaps is at present probably the safest and most economic way to guarantee strong-motion records from a large or great event within the next one or two decades. Six seismic gaps with a high probability to yield such data soon, if properly instrumented, are:

(1) San Andreas fault, Southern California
(2) Shumagin Islands, Alaska
(3) near Yakataga, Alaska
(4) Mexico (near Ometepec and Guerrero)
(5) Northeast Caribbean (Northern Lesser Antilles and Puerto Rico)
(6) near Valparaiso, Chile

Until quite recently, what was known about the dynamics of the source of an earthquake came primarily from observations of relatively long period waves (5-300 sec) recorded at rather great distances from the fault. These data provide average properties of the source, such as the fault orientation, the approximate rupture velocity, the average slip across the fault, and the total duration of the rupture process. In order to obtain more detailed information relating to the source mechanism, a knowledge of the short wave-length, high frequency nature of the source is needed. This can only be obtained by recording in the near-source region.

Fixed surface arrays must answer questions such as: How fast does the fault rupture grow, how smooth is this growth, how does the acceleration vary as a function of azimuth, and is the ground motion maximum at the fault or at some distance away from the fault? The spacing and the geometric pattern of the arrays must be designed to resolve as much of the source details as is possible with a surface installation. Arrays must be designed also to minimize the influence of local effects.

The principles that must be followed in the design of source mechanism arrays are:

1. Every effort must be made to minimize local and propagation path effects relative to source effects by placing (when possible) the station on similar competent rock sites near the

potential fault and the recording site. It is impossible to completely eliminate local and propagation path effects, or even to make these effects the same at all our recording sites. Therefore, to provide a means to check the magnitude of these effects on source mechanism data, recording sites have, in a few cases, been chosen which have different local conditions but are separated by distances small compared to the distance to the source.

2. Where possible, instruments should be placed so as to resolve the highest frequencies of interest. Also the design should be determined by the expected hypocentral depth and fault length of the potential earthquake.

Different types of fixed arrays will be required depending on the type of fault to be instrumented. Example array configurations for strike-slip, thrust and normal faults are presented in the Proceedings of the International Workshop on Strong-Motion Earthquake Instrument Arrays. These configurations provide useful guidelines for the deployment of fixed arrays, but other configurations might also be employed.

The strong-motion records collected by fixed surface arrays will answer a number of questions of great importance in earthquake engineering and strong-motion seismology. In particular, the following results are expected:

1. Description of the effects of the type of fault or fault mechanism (strike-slip, thrust, normal) on strong motion.

2. Spatial variation of strong motion in the near source region (20 km from fault) including radiation pattern and regions in which strong motion may be intensified by constructive interference of waves emanating from a moving rupture front.

3. Classification of the rupture process as unilateral or bilateral.

4. Measurement of rupture velocity which can be used in kinematic fault models and in the testing of rupture physics models.

5. Location of multiple events or events in which abrupt changes in rupture velocity and slip velocity occur. These portions of the fault may generate most of the high frequency components of strong motion. It will be possible to correlate their location with the surficial and sub-surface geology permitting generalization of the results to noninstrumented regions.

6. Records obtained in the near source region and along lines perpendicular to the fault will permit construction of reliable spatial attenuation functions which may depend on frequency and earthquake magnitude.

7. Comparison of recordings at a station for earthquakes of different magnitudes will be used to establish the degree of nonlinearity in the energy release process.

8. Fixed source mechanism wave propagation arrays will provide input data for other specialized soil-structure and structure response measurements.

3.3.2 DENSE THREE-DIMENSIONAL ARRAYS

An important factor in understanding and estimating local soil effects on ground motions and soil-structure interaction effects on structural response is the three dimensional nature of earthquake waves. To properly account for these effects it is necessary to know not only the peak ground acceleration and the frequency content of the earthquake (as measured by its Fourier spectrum or a set of response spectra) but also its wave content: types of waves, distribution of the seismic energy among these waves in different frequency ranges, direction of the waves, etc. Moreover if measurements in buildings are to be correlated with analytical predictions including foundation flexibility, one must have a good knowledge of the soil properties at the site.

For these purposes it is necessary to have available records of the motion at various points on the ground surface, along two mutually orthogonal directions, as well as at different depths. When placed in the free field such Dense-3D arrays would provide very valuable information on the wave content of the motions. From the surface instruments the apparent velocity of propagation of the waves and the incident angles of body waves can be estimated. From the records at various depths, one should be able to define further the types of waves and resolve a present controversy on the attenuation of motion with depth (of particular importance for the design of structures with significant embedment). It would appear that an array of 9 instruments on the surface and 3 instruments at various depths (as used in Japan) would be appropriate. The depths at which the instruments should be placed would be a function of the soil profile, but a maximum depth of 100 to 300 ft seems reasonable.

When instrumenting a structure for which soil structure interaction effects are deemed to be important, it is necessary to determine not only the translational components of motion but also the rotations of the base. Measurement of ground motions at various points on the surface of the soil, outside the building, would help to determine the wave content of the excitation and to estimate torsional input as well as possible filtering effects of the foundation. Measurement of motions at various depths under the building (up to a depth of 2 to 4 foundation radii) would help to validate theoretical prediction of interaction effects.

Research is needed in the construction, packaging, and installation of down-hole sensing elements. Outstanding problems include the long-term reliability and the accurate orientation and leveling of the three-component sensors, as well as the proper anchoring of the sensors inside the cased or uncased holes. These problems need to be solved before successful deployment of dense-3D arrays can be realized.

To maximize the return, it is logical to site dense-3D arrays at locations where 1) strong earthquakes are expected reasonably soon, 2) large-scale strong motion networks are existing, and 3) the subsurface structures of the sites are reasonably well-known. A brief survey of the U.S. according to this criteria indicates that the following sites are promising for the deployment of such arrays:

1. San Bernardino
2. Richmond-Berkeley area
3. Los Angeles Basin
4. Wasatch Valley area
5. Imperial Valley
6. Parkfield area

3.3.3 MOBILE ARRAYS

With the present state of knowledge concerning seismicity, the amount of available resources, the desirability of having dense arrays in the near source region and to maximize our chance of obtaining useful data in the United States, the establishment of MOBILE ARRAY of strong-motion instruments is necessary. It is recommended that such an array be operated as a national facility under some appropriate management structure.

Depending on the types of earthquakes (mainshock-aftershock, twin mainshock or "mainshock swarm") and the magnitude of the mainshock, one can obtain significant strong motions from M > 6 aftershocks or relatively weak motions from M5 or even smaller earthquakes. Also, if a significant prediction of a M > 6 earthquake is made, such an array can be used in the densification of existing networks or to provide the primary network for monitoring the strong motion of the event.

The deployment schemes should be planned ahead for various possible private contacts (for example EERI members, etc.). It is important that emergency logistics be planned and rehearsed so that quick response to major earthquakes can be made. Obviously, the instruments used in such work should have a large dynamic range.

Large earthquakes in the eastern United States are rare and far apart. But even a moderate earthquake near a population center or critical facility is a significant risk. Little is known about source and propagation properties effecting ground motions in this region.

Therefore, a mobile array of instruments would be extremely valuable as a complement to fixed stations in historically active areas.

3.4. STRONG MOTION INSTRUMENT NEEDS

There is little doubt that future strong-motion recording devices will be digital. With the rapid development of digital electronics industry, digital recorders will soon provide the most accurate, flexible, as well as inexpensive device for strong-motion instrumentation. The instrument characteristics outlined below are well within our current technological ability.

It is deemed desirable that the recording device have a bandwidth from 0.1 to 50 Hz and a dynamic range (using gain ranging) of 10^6. Internal clocks that provide absolute timing should have a drift rate not exceeding 10^{-7}. These clocks must be able to be reset from an external, portable master clock so that the precise relative timing can be obtained periodically and especially, immediately after a significant event. The sample rate should be 200 sps minimum to allow for reliable recording of 50 Hz signals after anti-aliasing filtering. It is suggested that pre-whitening filtering be investigated. Recording time should be as long as a cassette tape would last, with 20 minutes as a minimum. Temperature tolerance down to sub-freezing level is necessary for many applications.

It is desirable that recorders have "smart" triggers and pre-event memories of at least 5 seconds. The trigger threshold and full-scale range should be easily programmable to allow for studies of such things as aftershock sequences and refraction profiling. Routine, convincing instrument calibrations are necessary. The power drain of the recording system should be kept low enough so that at nominal triggering rate batteries need not be replaced more often than once every six months.

It is strongly encouraged that the instrument manufacturing industry set a standard recording format so as to facilitate the data exchange between user groups using equipment from different manufacturers.

The future use of digital recorders implies the adoption of sensors of the force balanced type (FBA). Of prime importance is that the performance of these FBA's is clearly known and easily calibrated. These sensors should have flat response up to 50 Hz, and draw less than 1 ma at +12 V dc. The three components of the sensor should be matched and have linear response over the bandwidth with a maximum acceleration of 2g. With simple modification, they should be capable of making measurements as high as 5g.

3.5. RECOMMENDED COOPERATIVE PROGRAM

In order to best achieve and maximize our efforts, it is proposed to instrument fault locations and structures within an area in a complimentary manner. Locations such as San Bernardino, Los Angeles, Hayward, Salt Lake City, Reno, Seattle, and the Mississippi Valley represent centers of population with the best chance of combining arrays to measure source mechanism, wave propagation parameters, structural response, and soil-structure interaction.

These cities have enough buildings of all types that can be instrumented in conjunction with the fault and transmission path studies to give direct comparison of building response with respect to distance from fault. All localities have the possibilities of a major earthquake of M7, or greater, though these are of differing probabilities. The SAN BERNARDINO REGION, LOS ANGELES BASIN, and the HAYWARD REGION have a somewhat higher probability of large earthquake occurrence and are herewith recommended as the highest priority sites for a cooperative strong-motion program.

The following combined instrumentation program is recommended for these sites:

1. Instruments should be located on the ground at approximately 5 km spacing for a distance of 50 km along the faultline. At right angles to the fault line should be located two arrays at the quarter points of the expected break. These arrays would have instrumentation at 5 km spacing and extend about 30 km each side of the fault. In addition, a dense array of instruments with variable spacing of 50 m to 500 m should be located between two stations on the fault line. A 3-D array should be placed in each region when sufficient confidence exists in the accuracy of placement and recordings.

2. Buildings should be selected and instrumented as indicated in Section 3.2.

3. Lifeline systems should be instrumented. The items in this category to be considered should include: bridges and overpasses, electrical sub-stations, dams, utility lines - gas, water, sewer, buried structures, reservoirs, water towers, railroad lines and utility stacks. The degree of instrumentation used should be of sufficient quantity to obtain information equivalent to that of the building instrumentation. The degree of variation shall be dependent on the particular site or sites chosen to be studied.

4. In addition, mobile strong-motion instruments should be installed in the free field to enhance the measurements obtained from fixed instruments.

CHAPTER 4

PROCESSING, CATALOGING, ARCHIVING AND DISSEMINATION OF STRONG-MOTION DATA

4.1 INTRODUCTION

Once suitable sites for seismic instrumentation are selected and instruments are installed, the sometimes long wait begins. The planning efforts and activities which lead to these installations would be of no avail if the instruments do not function. In addition, the data must be processed appropriately and made readily available. Today there are many instruments in the field and these operate with varying degrees of maintenance and calibration. Furthermore, in many cases information pertaining to the instrument site, which is necessary in order to make full use of the strong-motion records, does not exist or is not readily available.

The products and accuracy of standard data processing procedures[1] are reasonable for most engineering purposes. Specialized purposes may require additional analysis especially if low frequency information is required. It is anticipated that the expanded installation of digital recording systems will mitigate some of the problems of recording and digitization associated with film recording systems, but at present the number of digital instruments in the field is small.

Today there are several data "banks" that provide limited cataloging, archiving and dissemination. Two major services must emerge before awareness of available data and access to the data are assured. There must be cataloging (cross-referencing) of record information and there must be centralized archiving of the data itself. Data cataloging and archiving should include both U.S. and important world-wide earthquakes. It should be in a format that is universally accepted by both U.S. and foreign engineers and scientists.

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1. Standard data processing procedures are understood to be those employed by the major record processors, such as U.S. Geological Survey, California Division of Mines & Geology and University of Southern California.

4.2 PROBLEMS ASSOCIATED WITH STANDARD METHODS OF DATA PROCESSING

Standard methods for processing analog film accelerograph data[2] have produced reasonable results for most engineering purposes. However, recent research has uncovered possibilities for significant improvement. In particular, the instrument correction procedures and procedures for handling the long-period components of the data should be revised using the best techniques available from signal processing theory. It may be appropriate that some of the earlier important records be reexamined with a revised data processing procedure.

Some aspects of the digitizing process need careful scrutiny; particularly, the procedures for mating segmented records and the problem of possible biassing of acceleration peaks due to variability in trace width. Those involved in record processing should be aware of the serious consequences of scratches and other kinds of film damage on the results of automatic digitization. With great care exercised at every stage, the results of processing film records can be significantly improved. However, some problems, such as the loss of the initial portion of the motion, are inherent with the photomechanical instrument.

Conversion of film records into computer compatible format poses other problems. The timely availability of records depends on speedy conversion. Current procedures have reduced processing times, but manual intervention is still required in many situations. Thus, throughput rates of only one record per day are not unusual.

Quality control of the digitization process is a difficult matter. In-house digitization done by staff personally interested in the successful completion is generally acceptable; while quality control of work done by commercial operators without personal interest in the data is more difficult to assess. It would be highly desirable to develop standard test records to be submitted to different digitization systems and/or operators to verify realiability and quality. Multiple submission of the same data may also be considered.

Recent strong ground motion records exhibiting high acceleration levels have raised questions of signal clipping. Routine deployment of 2g instruments may be desirable. In addition to minimizing the potential for clipping, this would also alleviate the editing process in automatic digitization, while still giving sufficient resolution.

The timely deployment of reliable digital recorders would, on the surface at least, eliminate the majority of the above problems. Some of the potential advantages of digital recorders are indicated below.

1. Digitization. The digitization problems associated with variable trace width, manual intervention and loss of signal are

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2. Strong-motion instruments which record frequency modulated signals on magnetic tape are not considered herein.

most severe at times of high amplitude, the most important parts of the record. This problem will be overcome by the use of digital recorders. The problem of segmenting and matching parts of the film record which can give rise to significant errors in the integrated displacement records will also be eliminated.

2. Pre-event memory. The digital recorder has the capability of remembering and recording the initial portion of the ground motion which triggers the recorder. This provides significant new information, particularly for those important situations where the station is close to the earthquake source and when the early part of the record contains large accelerations. It also provides a sample of the quiescent baseline prior to the onset of motion which is useful in integration of the acceleration record.

3. Dynamic range. Most digital instruments employ 12-bit recording systems and are therefore capable of providing improved dynamic range over photographic recordings. Even without gain ranging, these instruments make possible the recording of 2g accelerations without sacrificing low level information. With increased numbers of stations there is a good possibility of recording motions in excess of 1g in special circumstances, so this may be an important consideration.

4. Gain ranging. Under certain circumstances, gain ranging can make it possible to obtain important data at low levels of motion for smaller earthquakes. Extending the range by a factor of 10 to 100, for example, may be the only way to obtain data on attenuation, structural response or soil-structure interaction in areas where large ground shaking is very infrequent.

5. Remote interrogation. The capability of telephone interrogation for both station status and data readout may result in a significant cost savings in operating a strong-motion network. Since personnel costs are a large part of the operating budget, the day may soon come when the additional costs of such equipment can be justified.

6. Multichannel capability. The incremental cost of recording channels and/or multiplexing is less for digital systems, making them more cost effective for large and complex recording systems designed for special studies of structures.

4.3 UNRESOLVED QUESTIONS CONCERNING DIGITAL INSTRUMENTS

In spite of their inherent advantages, experience with first generation digital instruments has indicated a number of potential problems. There is every indication that these problems are being resolved. However, it is important that the user be aware of their existence and nature. Some of the more important potential problems are indicated below.

1. New technology. A number of problems of field reliability relate to the learning curve for both manufacturer and users. Experience with new maintenance requirements has to be accumulated as does experience with new procedures for data handling.

2. Environmental problem with magnetic tape. Low temperature and contamination can produce tape reliability problems. Those can generally be circumvented by careful field procedures and attention to environmental conditions. For installations at temperatures below -10° F, it may be necessary to provide a heated enclosure. Continued developments by manufacturers can be expected to improve this situation.

3. Dropouts. There will always be the possibility of a small number of digital errors. It is possible, however, to provide enough redundancy that the occasional error can be corrected. Error rates should not exceed a few samples out of several million. The number of errors will be very sensitive to maintenance and testing procedures. It is important that progress along this learning curve be made as rapidly as possible.

4. Electronic interference. As with most electronic devices, some problems may exist for installations close to radio or television transmitters, and some attention will need to be paid to this problem for such installations.

5. Long-term storage. Under present conditions, digital tapes have to be rewritten at about a four-year interval. For a large archive, this could become a cumbersome and expensive process.

4.4 INSTRUMENT EVALUATION AND CALIBRATION

Underlying the quality of strong-motion data is the accuracy of the transducer, signal conditioning, and recording system. There is a need for each type of instrument to be evaluated experimentally to determine its accuracy, linearity, frequency response (both amplitude and phase responses and spurious resonances), cross-axis sensitivity and sensitivity to temperature changes.

There is a need for the standardization and documentation of procedures used to calibrate instruments prior to their deployment in the field.

4.5 ARCHIVING, CATALOGING AND DISSEMINATION OF STRONG-MOTION DATA

Current Programs

A large number of organizations (national, state and local government agencies, private and public utilities, universities, and a limited number of private organizations) are involved in the U.S. strong-motion instrumentation programs to varying degrees. From the standpoint of archiving, cataloging and dissemination of the strong-motion data, major programs at the U.S. Geological Survey and California Division of Mines and Geology have responded to user needs in the past and may be expected to continue to do so in the future, provided funding is maintained. A number of other smaller organizations have made arrangements with the U.S. Geological Survey or California Division of Mines and Geology to have their significant records processed and distributed, or have maintained this capability themselves. It appears that there are other groups who have not made provisions for data processing and distribution and who do not have this capability themselves.

The U.S. Geological Survey is the only U.S. organization that maintains a system (SMIRS - Strong-Motion Information Retrieval System) that can be easily and readily accessed by potential outside users (Converse, 1978). Users can retrieve information with any computer terminal and a 300 baud modem. The information that can be obtained from SMIRS is: 1) data on causative earthquakes, 2) data on strong-motion stations, and 3) data on recorded accelerograms. SMIRS is intended to provide limited information to aid the user, but does not provide the strong-motion records themselves or information relative to these records (although the system does indicate where these records may be obtained). SMIRS is generally limited to data from the western hemisphere, although it contains some information on large-magnitude earthquakes elsewhere.

The U.S. Geological Survey archives the originals of their own strong-motion records and those from other agencies they serve. Significant records are digitized and processed. These data are kept within the U.S. Geological Survey and duplicate data are sent to the National Geophysical and Solar Terrestrial Data Center (NGSDC)/NOAA in Boulder, Colorado for distribution to users. The U.S. Geological Survey presently honors limited requests for data, but in the future all requests for their data will be directed to NGSDC/NOAA.

The California Division of Mines and Geology operates the second largest strong-motion program in the United States. CDMG currently collects, processes, archives and distributes their own data upon request. As yet, they have made no formal provisions to send copies of their data to NGSDC/NOAA. Some smaller programs at California Institute of Technology, University of Southern California and Southern California Edison also maintain essentially the same capability and perform the same service as California Division of Mines and Geology. However, these services are not well publicized and the organizations involved have generally not made arrangements for sending the data to NGSDC/NOAA.

The Environmental Data Information Service of the National Oceanic and Atmospheric Administration (EDIS/NOAA) operates both a national (NGSDC) and world geophysical data center (WDC). Hypocentral, intensity, and tsunami data files are maintained for world-wide earthquakes. Global standard seismograms and strong-motion accelerograms are archived and cataloged (Morris, et al., 1977). Although the strong-motion records are generally confined to U.S. earthquakes, approximately 3,000 strong-motion records are on file. NGSDC/NOAA also has files of approximately 700 processed accelerograms from countries throughout the world. The degree of processing varies from digitized uncorrected to completely corrected accelerograms using methodologies originally developed at the California Institute of Technology (Trifunac and Lee, 1973). However, the processed strong-motion accelerogram files are not complete, especially for Japan and other countries outside the United States. Nearly all of the important U.S. records are with NGSDC/NOAA; however, many processed records are still in the possession of individual organizations.

EDIS/NOAA will supply any of their processed accelerograms to users upon written request. A modest fee is required to cover handling costs. NGSDC/NOAA has their strong-motion data cataloged to the extent that users can identify the records they would like to receive. However, the catalog is not sufficiently complete for research purposes.

Problem Areas

As a consequence of the large number of strong-motion programs, not only in the U.S. but throughout the world, a number of data management and distribution problems have arisen. There is a growing concern that, as the number of participating organizations and the strong-motion data base continues to increase, a significant amount of the data may not get into the hands of the user on a timely basis. This problem already exists to some extent and is likely to become worse. The major reason for this problem is the fragmentation of existing programs and the lack of coordination among them. As yet, no central organization has established specific guidelines, which would effectively coordinate and unify the efforts of all programs toward archiving, cataloging and disseminating strong-motion data.

One catalog exists (Crouse, et al., 1980) that contains comprehensive information on all significant world-wide accelerograms that have been digitized and published. This catalog has received limited distribution throughout the United States by NRC as a NUREG document, but the document is not in a form that is optimum for the general user. The catalog has been submitted to NTIS.

Recommendations

Based on the above observations, the following recommendations are made:

1. A minimum standard of documentation should be developed for existing and future strong-motion data collected by various agencies and organizations.

2. Strong-motion data should be archived and cataloged so that these data can easily and readily be obtained by users not only in the United States, but throughout the world.

3. A commitment should be made to continually update the catalog of strong-motion data so that it is kept current.

In item 1, the strong-motion data refers to the strong-motion records (unprocessed and processed) and to information pertaining to these records that is relevant for research purposes. For each record three general categories of information can be identified: accelerogram, recording station, and causative earthquake. Information in each of these categories that should be documented is as follows:

Accelerogram

- Date and time of earthquake
- Location (address) and identification (I.D.) number of recording station
- Earthquake magnitude and site intensity
- Source-site distances (epicentral, hypocentral)
- Amount and type of accelerogram processing
- Accelerogram characteristics (uncorrected peak acceleration, corrected peak acceleration, velocity and displacement, and RMS acceleration)

Recording Station

- Location, coordinates, and I.D. number
- Structure housing instrument (size and type)
- Type of instrument and location within structure
- Local geology (description and classification)

Earthquake

- Date and time
- Location description and hypocentral coordinates (including location uncertainty if known)
- Magnitudes (M_L, M_S, M_W, M_b, M_{JMA}, etc.)
- Maximum intensity
- Source dimensions (length, width, radius, area)
- Seismic moment and stress drop
- Source rupture characteristics (fault type, strike, dip, displacement, slip and rupture directions, rupture velocity)

Each organization maintaining strong-motion instruments should document the above information for every accelerogram digitized. It is recognized that some of this information, such as earthquake source parameters, may not become available for some time. However, organizations should attempt to maintain this documentation to the best of their ability in an organized manner. Copies of this documentation should routinely be forwarded to the U.S. Geological Survey Seismic Engineering Branch for inclusion into the SMIRS data base. It is important that each organization submit as much of this information as possible to the USGS immediately after the records are processed. Missing information should be supplied as it becomes available.

As far as the actual records are concerned, organizations that process strong-motion accelerograms should send magnetic tapes or card decks of the accelerograms to NGSDC/NOAA with the minimum documentation described above. A brief user's guide must accompany tapes.

Accelerograms that are not digitized should be archived by the responsible agency and a minimum amount of information, such as date and time of the recording, peak acceleration and station, should be documented. Copies of this documentation should be forwarded to the U.S. Geological Survey for possible inclusion in the SMIRS system.

Each organization deploying strong-motion instruments should maintain a comprehensive file of information on their recording stations. This should include information on: 1) location (address and coordinates), 2) contact person and phone number, 3) access, 4) soil boring or other local geologic data, 5) location and orientation of instruments within a structure including, if applicable, 6) type, model number, installation date and performance specifications of each instrument, and 7) a record of instrument servicing and maintenance. Data sheets containing at least the address, coordinates, local geologic description, type of structure and instrument locations within structure, and instrument type for each station should be forwarded to the U.S. Geological Survey so that a strong-motion station catalog similar to the U.S. Geological Survey (1977) catalog for the western hemisphere can be maintained on a continuing basis.

Finally, the catalog (Crouse, 1980) containing the information on world-wide accelerograms which have been digitized and published, should be made available to the engineering and seismological communities throughout the world. As a minimum, the catalog should be put into a format convenient to all users and distributed to NGSDC/NOAA and the U.S. Geological Survey for inclusion in SMIRS. A magnetic tape of the data and user's guide together with the catalog would be sufficient. This would require a minimal effort and expense. Funds should be allocated for revising and updating the catalog periodically. A need presently exists for this activity.

4.6 CONCLUSIONS

In conclusion, it is strongly recommended that the technical community vigorously promote the following activities:

1. Revise instrument correction procedures and filtering procedures used in processing strong-motion data by implementing the best techniques available from signal processing theory.

2. Encourage the development and deployment of digital strong-motion recorders.

3. Standardize the documentation of instruments, calibration and installation site.

4. Centralize the cataloging and storage of strong-motion data. Utilize the U.S. Geological Survey SMIRS retrieval system for cataloging and the National Oceanic and Atmospheric Administration (NOAA) as the central repository for strong-motion data.

CHAPTER 5

PROGRAM MANAGEMENT AND FUNDING

5.1 INTRODUCTION

The deployment and maintenance of instrumentation for recording strong earthquake ground motion involves some special issues which present management and funding problems. As it may be many years before a significant record is obtained at a particular site, careful attention is required over a long period of time to keep the recording instrumentation in working order. The long time periods involved, requiring several generations of devoted workers, also makes stability of funding of utmost importance.

The U.S. strong-motion program, which will have its 50th anniversary in 1983, has so far been able to cope with these basic problems sometimes with difficulty, but in general with marked success. It appears that such problems will become even more troublesome in the future because of: 1) increasing size and diversity of networks, 2) increasing complexity and cost of the basic instrumentation and maintenance, 3) rising standards of accuracy and of data processing and presentation, and 4) wider range of interested user groups for the basic data.

5.2 PROGRAM MANAGEMENT

Instruments for recording strong earthquake shaking are at present installed and maintained by a number of different agencies and organizations as indicated in Chapter 2.

Each of the organizations maintaining strong-motion instruments has its own particular interest in earthquake hazards, and the instruments which they deploy are located to provide information relating to these interests. The effectiveness of these individual programs could be substantially improved through greater cooperation and coordination between the various concerned groups. This includes users as well as organizations involved in data acquisition. Users of strong-motion data should become better acquainted with ongoing strong-motion programs and the availability of data. Conversely, the managers of strong-motion programs should become better acquainted with the needs of the data user.

5.2.1 NATIONAL COMMITTEE ON STRONG EARTHQUAKE MOTION

At present there are many different organizations engaged in the installation and maintenance of strong-motion instrumentation, and in data processing and dissemination of information. A number of these organizations have had long experience in the field, are well-organized, and well-funded and for various administrative reasons would find it impracticable to turn over their basic responsibilities in the subject to any central agency. Therefore, the idea of establishing one central group of any type as the headquarters for a U.S. National Strong-Motion Program would not be a practicable approach.

At the same time, it would be a definite advantage if the individual strong-motion programs in the United States could be viewed as parts of a National Strong-Motion Program and the individual efforts more effectively coordinated. It is believed that this can best be accomplished by the formation of a National Committee on Strong Earthquake Motions. The following recommendation is therefore made.

<u>Recommendation.</u> It is recommended that the Universities Council for Earthquake Engineering Research and the Earthquake Engineering Research Institute jointly create a National Committee on Strong Earthquake Motions; this to preferably be accomplished through existing mechanisms involving the National Academy of Sciences, the National Academy of Engineering, and the National Research Council.

<u>Formation and Constitution</u>

1. The Universities Council for Earthquake Engineering (UCEER) Research and the Earthquake Engineering Research Institute (EERI) should immediately take the necessary steps to establish and organize a National Committee on Strong Earthquake Motions (NCSEM). These organizations should attempt to secure organizational support for the NCSEM from the National Academy of Sciences, and the National Academy of Engineering, through the National Research Council.

2. The membership of the NCSEM should consist of approximately ten persons. The initial membership should be based on nominations from UCEER and EERI. Subsequent appointments should be drawn from all nationally recognized organizations involved in strong-motion activity. A chairman should be selected from the membership. The membership should be representative of all national groups involved in acquisition and use of strong-motion data. Sub-groups with consulting members from outside the main Committee should be formed as appropriate. Liaison

members should be appointed from major individual strong-motion programs.

3. The NCSEM should meet at specified, regular intervals, such as two or three times per year.

4. The initial NCSEM should draft bylaws which should be approved by both the Universities Council for Earthquake Engineering Research and the Earthquake Engineering Research Institute.

5. Funding for the operation of the Committee should be sought by NCSEM from diversified sources representing a balance of interested groups using data on strong earthquake motions.

Functions. The main activities of the NCSEM shall include, but not be limited to the following:

1. Develop and maintain a National Strong-Motion Program Plan which provides for the participation of all those interested in the recording of strong earthquake motions of the ground and of structures, and in the processing and dissemination of strong-motion data.

2. Formulate objectives which support the various needs of research workers, engineering designers, industry, government agencies, and others, for strong-motion data and information.

3. Convene workshops, seminars, etc., on strong motions in order to develop appropriate positions.

4. Advise public and private organizations on policies and programs.

5. Assure that appropriate catalogs, directories, and plans are available in the field, and assist in preparation of such material if appropriate.

6. Review existing programs for recording strong motions, for processing data, and for archiving data and make evaluations and recommendations for their improvement.

5.2.2. EXISTING NSF/USGS STRONG-MOTION PROGRAM

The first U.S. strong-motion program was started in the early 1930's and was operated until 1970 by the U.S. Coast and Geodetic Survey. The program was then transferred to the National Oceanic and Atmospheric Administration which operated the program until 1973, when the U.S. earth sciences program was completely reorganized. Under this reorganization, the National Science Foundation was designated as lead agency for earthquake engineering and the U.S. Geological Survey was designated as lead agency for seismological research. Under this reorganization the National Science Foundation was assigned the responsibility for funding the U.S. Strong-Motion Program, with operation and management responsibility assigned to the U.S. Geological Survey. This division of responsibilities has created certain organizational and management problems which have inhibited the optimum development of the program.

In view of recurring problems of management and funding within the Seismic Engineering Branch of the U.S. Geological Survey which are of direct importance to the whole U.S. Strong-Motion Program, this specific situation deserves careful examination. After extended exploration of the matter, four possible courses of action have been identified regarding the NSF/USGS program. These are:

1. Maintain the status quo, under which the Seismic Engineering Branch receives funds awarded to the U.S. Geological Survey by NSF. It is understood that this is a viable budgetary option through 1982.

2. Transfer NSF funds to the U.S. Geological Survey through the Office of Management and Budget sufficient to support the Seismic Engineering Branch program at essentially the present level.

3. Use present NSF funds to support the Seismic Engineering Branch operation under some new organization.

4. Use present NSF funds for a new strong-motion program, perhaps including some of the elements of the present Seismic Engineering Branch program, but under an entirely new organization.

Option 1) is rejected as it is felt that the status quo is not accomplishing the desired objectives. After a detailed consideration of the remaining options, the following recommendation is made.

Recommendation. It is recommended that the Ad Hoc Study Panel on Strong Motion recently constituted by the Earthquake Engineering Research Institute and the Universities Council for Earthquake Engineering Research consider the possible courses of action listed above and any other options deemed appropriate and make a specific recommendation by August 31, 1981. If the Study Panel is unable to reach a decision by that date, it is recommended that option 2) be implemented by NSF and USGS.

5.3 FUNDING

For the reasons indicated in Section 5.1, long-range stability of funding is a most important factor for any Strong-Motion Instrumentation

Program. As indicated there, it is also to be expected that in the future the overall cost of such programs will increase rapidly. The relatively informal way in which such programs have been supported in the past will clearly no longer be adequate to the importance of the subject. In particular, it may be noted that many, if not most, of the principal users of the strong-motion data make no direct or even indirect contribution to the financial support of the program. In the interests of providing a greater diversification of support, it would be advantageous to more actively canvas strong-motion data users and potential users for financial support, and to provide a means through which such funding could be accommodated in various forms and at various levels.

The users of strong-motion earthquake data, in a broad sense, are all those components of an industrialized society upon which an earthquake could have an adverse effect and, hence, should give consideration to earthquake protection. Although it is true that the ultimate beneficiaries of earthquake data are the citizens of the country, the immediate users of the data are the various research groups, industries, federal government agencies, state and local government agencies that are concerned about earthquake hazards. A partial list of such users is given below.

<u>Research Organizations</u>

University research staff and students
Consulting research institutes
Specialized engineering consultants

<u>Industry</u>

Oil companies
Manufacturing companies
Communications companies
Chemical companies
Nuclear power industries
Public utilities
Architectural and engineering firms
Construction industry
Insurance industry
Banking and savings and loan industry
Trade associations

<u>Federal Government Agencies</u>

Nuclear Regulatory Commission
Bureau of Reclamation
Corps of Engineers
Veterans Administration
Federal Housing Administration
Federal Highway Department

Housing and Urban Development Agency
Department of Energy
Department of Defense
Tennessee Valley Authority
Military Installations
National Bureau of Standards
U.S. Geological Survey

<u>State and Local Agencies</u>

Highway and bridge departments
Water and resource agencies
City building departments
Mass transit systems
Planning commissions
Environmental impact agencies
School districts
Hazard evaluation agencies

In light of the needs for funding stability, and an increased level of funding and greater diversity of funding for the U.S. strong-motion program, the following recommendation is made.

<u>Recommendation.</u> It is recommended that a vigorous effort be made to increase the level and diversity of funding for the U.S. Strong-Motion Instrumentation Program.

5.4 STATE AND LOCAL STRONG-MOTION PROGRAMS

One of the most effective strong-motion programs from the point of view of both management and funding is the State of California Program conducted by the Division of Mines and Geology. Many features of this program might well be adapted or modified to suit conditions in other states or municipalities.

It is realized that the strong-motion programs appropriate to various states and municipalities may differ widely, but it is believed that the experience gained in the State of California might make useful contributions to the development of suitable programs in other areas. Representatives of the State of California have stated their willingness to cooperate fully with advice and assistance in the formulation of such plans. The following recommendation is therefore made.

<u>Recommendation.</u> It is recommended that states and local municipalities in zones of high seismic risk examine the program of the State of California in the organizing and funding of strong-motion instrumentation systems to determine the extent to which it might be adapted or modified to meet conditions elsewhere. It is understood that the California State Strong Motion Instrumentation Program offers to provide advice and assistance in the planning and development of such programs.

REFERENCES

Converse, A. (1978). "Strong Motion Information Retrieval System User's Manual," U.S. Geological Survey Open File Report 79-289.

Crouse, C.B., Hileman, J.A., Turner, B.E. and Martin, G.R. (1980). "Compilation, Assessment, and Expansion of the Strong Motion Earthquake Ground Motion Data Base,' Report to Lawrence Livermore Laboratory by Fugro, Inc.

Hart, G.C., Rojahn, C. and Yao, J.T.P. (1980). Proceedings, Workshop on Interpretation of Strong-Motion Earthquake Records Obtained in and/or Near Buildings, April 1-2, 1980, San Francisco, California, UCLA, Los Angeles.

Iwan, W.D. (Ed.) (1978). Proceedings, International Workshop on Strong-Motion Earthquake Instrument Arrays, May 2-5, 1978, Honolulu, Hawaii, California Institute of Technology, Pasadena.

Morris, L., Smookler, S. and Glover, D. (1977). "Catalog of Seismograms and Strong-Motion Records," World Data Center A for Solid Earth Geophysics," National Oceanic and Atmospheric Administration, Report SE-6.

Trifunac, M.D. and Lee, V. (1973). "Routine Computer Processing of Strong-Motion Accelerograms," Report No. EERL 73-03, California Institute of Technology, Pasadena.

USGS (United States Geological Survey) (May 1977). "Western Hemisphere Strong-Motion Accelerograph Station List - 1976," Open File Report No. 77-374.

APPENDIX A

STRONG-MOTION EARTHQUAKE INSTRUMENTATION SURVEY

A survey of strong-motion earthquake instrumentation programs is being made in conjunction with the U.S. National Workshop on Strong-Motion Earthquake Instrumentation being April 12-14, 1981. The participation of your organization is important if this survey is to be meaningful. Would you please fill out the following questionnaire answering the applicable questions as concisely as possible and return it within ten days to the address indicated below. Thank you.

1. Name of organization

   ____

2. Name and title of individual completing questionnaire

   ____

   ____

3. Please give a brief description of your organization's strong-motion instrumentation program.

   ____

   ____

   ____

   ____

4. Does your organization have stated goals and/or objectives for its strong-motion program? If so, what are they?

   ____

   ____

5. Does your organization have an established strategy or philosophy for the deployment of instruments? If so, what is it?

____

____

6. How does your organization select strong-motion sites?

____

____

7. Who installs the instruments that are part of your program (e.g., an outside organization, a separate group within your organization, etc.)?

____

____

____

8. How are the strong-motion stations in your program maintained?

____

____

____

9. What is the present number of strong-motion instruments deployed under your organization's program (if possible, please attach a list of your strong-motion stations)?

____

____

10. What is the approximate yearly number of records processed and archived by your organization in each of the following categories? Peak Acceleration: 0.025g-0.05g ______; 0.05-0.10g ______; 0.1-0.25g ______; 0.25-0.5g ______; 0.5g ______.

11. How are your strong-motion records processed and by whom?

____

____

____

12. Generally speaking, how soon after an event is data available for distribution?

____

____

13. Where is your strong-motion data archived and in what form?

____

____

14. How is strong-motion data used by your own organization?

____

____

15. How are potential outside users of your data notified of its availability?

____

____

16. How is data made available to the user community? (Please indicate standard data charges if appropriate.)

____

____

17. What is your approximate annual budget...

    for installation of new instruments? ____________

    for maintenance? ____________

18. What is the major source of funding for your program?

____

____

19. What is your best estimate of the number of new instruments that will be installed under your organization's program during the next year?

20. Do you have any plans to change the direction of your strong-motion activity in the future? If so, what are your future plans?

21. Comments

Please return to:

Professor W. D. Iwan
Mail Code 104-44
California Institute of Technology
Pasadena, CA 91125

APPENDIX B

LIST OF ORGANIZATIONS AND CONTACT PERSONS

Bureau of Reclamation
Code 1631
P.O. Box 25007
Denver, CO 80225
Contact: A. Viksne
Telephone: (303) 234-5732

California Division of Mines & Geology
California Division of Mines & Geology
Strong Motion Studies
2811 O Street
Sacramento, CA 95816
Contact: T. M. Wootton
Telephone: (916) 322-3105

California Department of Transportation
Office of Structures Design
P.O. Box 1499
Sacramento, CA 95816
Contact: J. Gates
Telephone: (916) 445-1439

California Department of Water Resources
1416 Ninth St.
P.O. Box 388
Sacramento, CA 95802
Contact: P. Morrison
Telephone: (916) 445-8064

City of Tacoma, Washington
Public Works Department
Building Division
930 Tacoma Ave. So.
Tacoma, WA 98402
Contact: C. A. Pearson
Telephone: (206) 593-4292

City of Los Angeles
Department of Building & Safety
200 N. Spring St., Room 421
Los Angeles, CA 90012
Contact: J. O. Robb
Telephone: (213) 485-3435

Department of Energy, Las Vegas
URS/John A. Blume & Associates
Sheraton-Palace
130 Jessie St.
San Francisco, CA 94105
Contact: J. Blume
Telephone: (415) 397-2525

Department of Energy
San Francisco Operations Office
Energy Technology Engineering Center Project Office
P.O. Box 1446
Canoga Park, CA 91304
Contact: R. E. Fenton
Telephone: (213) 341-1120

East Bay Municipal Utilities District
2130 Adeline St.
P.O. Box 24055
Oakland, CA 94623
Contact: W. F. Anton
Telephone: (415) 835-3000

Federal Highway Administration
Fairbanks Highway Research Station
Office of Research, HRS-11
Washington, D.C. 20590
Contact: J. D. Cooper
Telephone: (202) 557-5272

Idaho National Engineering Laboratory
EG & G
P.O. Box 1625
Idaho Falls, ID 83401
Contact: J. J. King
Telephone: (208) 526-3600

Lamont Doherty Geological Observatory
Columbia University
Palisades, NY 10964
Contact: Klaus Jacob
Telephone: (914) 359-2900

Lawrence Livermore National Laboratory
P.O. Box 808, L-95
Livermore, CA 94550
Contact: A. F. Shakal
Telephone: (415) 422-1100

Los Angeles City Department of Water & Power
P.O. Box 111, Room 1455
Los Angeles, CA 90051
Contact: L. Lund, L. Escalante
Telephone: (213) 481-6150

Los Angeles County Flood Control District
5525 E. Imperial Highway
Southgate, CA 90280
Contact: M. Johnson
Telephone: (213) 861-0316

Metropolitan Water District of Southern California
1111 Sunset Blvd.
P.O. Box 54153
Los Angeles, CA 90054
Contact: G. F. Horowitz
Telephone: (213) 626-4282

Pacific Gas & Electric
77 Beale St.
San Francisco, CA 94106
Contact: D. Steinhardt
Telephone: (415) 781-4211

Sacramento Municipal Utility District
6201 "S" St.
Sacramento, CA 95813
Contact: D. Raasch
Telephone: (916) 452-3211, X514

San Diego Gas & Electric
P.O. Box 1831
San Diego, CA 92112
Contact: J. C. Burton
Telephone: (714) 235-7450, X450

Southern California Edison
P.O. Box 800
Rosemead, CA 91770
Contact: T. A. Kelly
Telephone: (213) 572-3290

Stanford University
The John A. Blume Earthquake Engineering Center
Department of Civil Engineering
Stanford, CA 94305
Contact: H. C. Shah
Telephone: (415) 497-4125

State of Washington
Department of Transportation
Bridge Engineering
Highway License Building
Olympia, WA 98504
Contact: U. Vasishth
Telephone: (206) 753-7205

State University of New York, Binghampton
Department of Geological Sciences
Binghampton, NY 13901
Contact: F. T. Wu
Telephone: (607) 798-2512

U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180
Contact: B. Ballard, F. McLean
Telephone: (601) 636-3111

University of Alaska
Geophysical Institute
Fairbanks, AK 99701
Contact: H. Pulpan
Telephone: (907) 479-7558

University of Nevada, Reno
Department of Civil Engineering
Reno, NV 89557
Contact: B. Douglas
Telephone: (702) 784-6937

University of Washington
Geophysics, AK-30
Seattle, WA 98195
Contact: S. Smith
Telephone: (702) 543-8020

University of Southern California
University Park
Los Angeles, CA 90007
Contact: T. Teng, M. Trifunac
Telephone: (213) 743-6124, 743-2987

U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025
Contact: R. Borcherdt
Telephone: (415) 323-8111, X2755

University of California, San Diego
Institute of Geophysics & Planetary Physics, A-025
La Jolla, CA 92023
Contact: J. G. Anderson
Telephone: (714) 452-2424

Union Carbide Corporation
Nuclear Division, Bldg. 9733-2
P.O. Box Y, MS 1
Oak Ridge, TN 37830
Contact: J. E. Beaver
Telephone: (615) 574-9786

Veterans Administration
Structural Division
6732 Deland Dr.
Springfield, VA 22152
Contact: R. D. McConnell
Telephone: (292) 389-3103